CHEMICAL ESSAYS.

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ADVER-

ADVERTISEMENT.

I Have every reaſon to be ſatisfied with the reception which has been given to my two former volumes of Chemical Eſſays. My deſign was to have publiſhed two others on the ſame plan; but this is the laſt for which I ſhall ever preſume to intreat the indulgence of the public. I perceived, as I proceeded in the work, that *two* additional volumes would not contain half the materials which I had collected; and deſpairing of ever finding leiſure to arrange the whole, I have contented myſelf with putting into this volume, what gave me the leaſt trouble in reviſing. For ſeveral months I have had great reaſon to believe, that an attention to health ought to occupy that leiſure, which I have hitherto beſtowed on the ſtudy of chemiſtry. It is a ſtudy of ſo bewitching a kind, that few perſons can cultivate it with moderation, or fail of feeling ſymptoms of that diſorder which *Beccher* in ſpeaking of himſelf, deſcribes in the following terms,*—*cui nec Aulæ Splendor, nec æconomiæ ratio, nec famæ integritas, nec ſanitatis vigor, quicquam præ carbonibus, venenis, fuligine, follibus, et furnis valere poteſt.*

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* Phy. Subter. Præ.

ESSAY I.

OF BITUMENS AND CHARCOAL.

THE analyſes of pitcoal and of different woods, mentioned in the laſt Eſſay, may ſerve as inſtances of the products obtainable by diſtillation from bituminous and vegetable ſubſtances in general. They all of them yield water impregnated with an acid, and often alſo with a volatile alkaline ſalt, air, oils of different colours, weights, and conſiſtences, and a black coaly reſiduum. The bitumens generally taken notice of by writers on Natural Hiſtory are, with reſpect to their conſiſtence, either as fluid as oil, or as thick and tenacious as tar, or quite ſolid. The fluid bitumens are two, *Naptha*, and *Petroleum*, or rock-oil. Theſe are oils which differ from each other in colour and conſiſtence, and ſome other properties; the naptha is pale, light, and very inflammable; the petroleum is yellow, brown, or blackiſh, heavier and leſs inflammable than naptha: its difference from naptha is attributed to its containing a greater quantity of acid in its compoſition. Both theſe oils are found in many parts of the globe, either floating on ſpring water, or dripping from the crevices of rocks. *Mineral pitch* is a bitumen which differs from petroleum in being thicker, heavier, and more glutinous; it was formerly found in the environs of Babylon, and conſtituted, according to Vitruvius, when mixed with lime, the cement which was uſed in building the walls of that city. At preſent it is met with in ſeveral parts of Europe, and in America, where it drips from rocks, and is called by us *Barbadoes tar:* it has a very offenſive ſmell, and great tenacity, and is called by the inhabitants of Auvergne, in France, where it exudes from the earth, and ſticks to the feet, devils dung. The *Aſphaltum*, or *jews-pitch*, is a bitumen much reſembling mineral pitch; it is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah ſtood, otherwiſe called the *Dead ſea*, or the lake *Aſphaltes*, from a Greek word denoting a bitumen. This lake in the time of Eſdras yielded Bitumen—*remember what I did to Sodom and Gomorrah, whoſe land lieth in clods of pitch*[*]. The bitumen floating upon the ſurface of the ſalt water, is condenſed by the heat of the ſun into a ſolid form, and is gathered by the Arabs on the ſhore where it is thrown. It is ſaid to be the ſame ſubſtance which the Egyptians uſed in embalming their mummies, and it was called by them *mumia mineralis*.[†] This bitumen has been found in many places of Aſia and Europe, as well as on the ſhores of the Dead Sea; all that we meet with in the ſhops, is either an artificial compoſition, or an European aſphaltum, the Eaſtern ones being ſeldom brought into Europe, but uſed by the natives either as pitch for their ſhips, or as an ingredient in varniſhing, or dying wool.

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[*] Eſd. B. 2. c. 2.

[†] Haſſelquiſt's Voy. p. 285.

There is a very curious experiment which illuſtrates the relation which theſe four bitumens bear to each other. The moſt tranſparent oil of turpentine, reſembling naptha, may be changed into an oil reſembling petroleum, by mixing it with a ſmall portion of the acid of vitriol; with a larger proportion of the acid the mixture becomes black and tenacious, like Barbadoes tar; and the proportions of the ingredients may be ſo adjuſted, that the mixture will acquire a ſolid conſiſtence, like aſphaltum. This experiment teaches us to conclude that naptha, petroleum, Barbadoes tar, and aſphaltum, differ chiefly from each other, with reſpect to the quantity of acid which enters into their compoſition; and the ſubſtances procured by diſtilling pitcoal, or reſinous vegetables may furniſh no improbable conjecture concerning the origin of theſe bitumens.

Let us ſuppoſe then a ſubterraneous fire to be ſituated in or near a ſtratum of pitcoal, of turf, of foſſil wood, or of any other ſuch bitumenous matter; it is manifeſt that the inflammable air, and the different kinds of oils, which were collected by diſtilling ſmall portions of theſe ſubſtances, would be elevated by the heat into the crevices of the ſuperincumbent ſtrata; the light and pale oil would be a ſort of naptha, or petroleum, the black and tenacious oil would be a Barbadoes tar, and this might be ſo dried by the heat as to become an aſphaltum. The oils not being miſcible with water, would be found floating upon its ſurface, as it iſſued out of the bowels of the earth, and being very inflammable, might conſtitute burning wells, ſuch as have been met with near Wigan, at Broſely, and in many other places: or where the oil did not meet with water, or was too heavy to float on it, we may conceive that it would impregnate the porous ſtrata of ſeveral kinds of ſtones and earth. It has been obſerved in another place,* that they formerly obtained a ſort of tar, from a ſtone at Broſely, and the ſtratum, which is called *ſhale* in Derbyſhire is ſo ſtrongly impregnated with oil, that it will burn

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* Vol. 2. p. 347

of itſelf, when ſet on fire: the workmen in digging through the black ſtone, which is incumbent on the ſhale, ſometimes meet with cavities containing a thick black oil, which has oozed out of the ſurrounding ſtone. One of the greateſt *ſoughs*, or ſubterraneous paſſages, which has, perhaps ever been formed in Great Britain, is that which is called Hell-car ſough, in Derbyſhire; this ſough is driven through a ſtratum of ſhale, and the workmen are much troubled with inflammable air, which generally breaks into the ſough, through the ſame crannies which give paſſage to little ſtreams of water: they ſecure themſelves from the air, by keeping great fans conſtantly in motion; for the inflammable air, being lighter than common air, floats near the roof of the ſough, and being drawn down from thence, and mixed with the common air by the motion of the fans, it is circulated in the ſough without danger. I am ſenſible that inflammable air may be produced by various other ways, as well as by the application of heat, to bitumenous ſtrata; but as bitumens do yield inflammable air by diſtillation, it is probable enough, that ſuch as is met with in bitumenous ſtrata, may ſometimes at leaſt, be referred to the action of a fire, ſituated, perhaps, at too great a diſtance from the ſurface of the earth, to produce any other ſenſible effect.

In the Duchy of *Modena* in Italy, there is a remarkable rock, which confirms very much the notion of oils and pitchy ſubſtances, being ſeparated from bitumens by a kind of ſubterraneous diſtillation. The inhabitants of the diſtrict, by piercing the ſides of this rock, at different diſtances from its ſummit, obtain oils of different natures, thickening and growing heavier and deeper coloured, as the canals through which they flow approach to the ſurface of the earth; at the diſtance of a few feet below the ſurface, they find a very thick oil, which in digging deeper becomes ſoft as butter, and at ſtill a greater depth, it is found to be as ſolid as pitch.

Beſides *pitcoal* and *aſphaltum*, there are three other ſolid bitumens which deſerve to be. mentioned—*Jet*—*Amber*—*Ambergris*. Jet ſo much reſembles cannel coal in its colour, in its hardneſs, in its receiving a poliſh, in its not ſoiling the fingers when rubbed upon it, and in other properties, that many authors confound the two ſubſtances together; and indeed they agree in ſo many qualities that it is ſomewhat difficult to ſay in what they diſagree. Jet, however, when warmed by friction, has the property of attracting bits of ſtraw, feathers, and other light bodies; but I never obſerved this property in any of the cannel-coals which I have tried. This property, if it may generally be relied on, as appertaining to jet, and not to cannel coal, is a very eaſy characteriſtic, by which theſe ſubſtances may be diſtinguiſhed from each other. Jet is ſaid to be found only in ſmall detached pieces, and that it is thereby diſtinguiſhable from cannel coal, which is found in large beds. Some think that the woody fibrous tiſſue of jet, may ſerve to diſtinguiſh it from cannel-coal, but whoever examines large quanties of this kind of coal, will ſee many pieces which much reſemble wood in texture. The weight of a cubic foot of cannel-coal is 1273 ounces; a cubic foot of jet is ſaid by one author to weigh 1238,[*] by another 1180 ounces.[†]

The natural hiſtory of *Amber* is very obſcure. This bitumen was for a long time thought to be reſtricted to the coaſts of Pruſſia, on the Baltic Sea. It was ſuppoſed to owe its origin to the exudations of certain trees on the coaſt of Sweden, which falling into the ſea, were there hardened by the continual action of the ſalts, and thence carried by particular winds to the open coaſts of Pruſſia. This opinion was ſupported by, and formed to account for, the ants, flies, ſpiders, leaves of trees, and other terreſtrial matters, which are almoſt always found incloſed in pieces of amber, and which no doubt muſt be admitted, as proving its being originally in a fluid ſtate. In Pruſſia they not only gather amber on the ſea coaſt, but they frequently find it at the depth of eight or ten feet beneath the ſurface of the earth, but at no great diſtance from the ſea. The ſuperincumbent ſtrata are ſand, clay, foſſil-wood, pyrites, ſand again, in which the amber is found, ſometimes in detached pieces, ſometimes in little heaps. This diſtribution of the ſtrata, where amber is found, together with their proximity to the ſea, has made it with ſome degree of probability be imagined, that this mineral owed its ſituation to the inundation and receſſion of the ſea, and that it was derived partly from an oil ariſing from the decompoſition of vegetables by ſubterraneous fires, and partly from a mineral acid. Amber is frequently found in Italy, where they have no foſſil-wood, but great plenty of petroleum.

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[*] Martin, [†] Lewis, Newm. Chem.

The natural hiſtory of *Ambergris* is as uncertain as that of amber, unleſs we admit the deſcription which has been lately given of its origin, as the true one. We are told that ambergris is a part of the *Cachalot* or *Spermaceti-whale*. " It is found in this animal, in the place where the ſeminal veſſels are uſually ſituated in other animals.

It is found in a bag of three or four feet long, in round lumps, from one to twenty pounds weight, floating in a fluid rather thinner than oil, and of a yellowiſh colour. There are never ſeen more than four at a time in one of theſe bags; and that which weighed twenty pounds, and which was the largeſt ever ſeen, was found ſingle. Theſe balls of ambergris are not found in all fiſhes of this kind, but chiefly in the oldeſt and ſtrongeſt.*" This account ſeems probable enough, for ambergris is a fine perfume, and we know that other perfumes, ſuch as civet, muſk, and caſtor, are ſituated in the inguinal regions of the civet cat, the muſk animal and the beaver.

All vegetable, and bitumenous,

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* Goldſmith's Nat. Hiſt. Vol. vi. p. 220.

and indeed all animal ſubſtances, leave, after their volatile principles have been ſeparated by diſtillation, a black coal. Theſe coals differ ſomewhat from each other, with reſpect to their proneneſs to catch fire, and their ability to ſupport it, but I will content myſelf with examining the nature of the reſidue, from the diſtillation of wood.

This reſidue does not differ from what is generally called charcoal; the ſlighteſt attention to the manner of obtaining this reſidue, and of making charcoal, will convince us, that no difference ought to be expected. When the wood is diſtilled, its communication with the external air is obſtructed, its volatile parts are elevated from it, by the heat to which it is expoſed, and the reſidue is that part of the wood which remains after all the volatile parts are driven off. In making charcoal they conſtruct a pile of wood upon the ſurface of the ground, they cover the pile with a coating of turf, or other ſubſtances, and make the coating ſo compact, that it will not admit of air, except through ſome little round holes, which are purpoſely made in it, and which can be ſtopped at pleaſure. When the pile, thus conſtructed, is ſet on fire, part of the oil of the wood is conſumed during the burning of the pile, the other part, together with the air and water contained in the wood, is evaporated, and there remains, when the operation is finiſhed, the earthy part of the wood, called in that ſtate, charcoal. Thus the making of charcoal is a kind of diſtillation, for the coating which ſurrounds the pile of wood, may be compared to a retort.

Henckel informs us, that 150lbs. of oak, will produce 62 lbs. of charcoal*; but he does not inform us whether the oak was dry or green, whether it had its bark on or was peeled, whether it was all heart of oak, or partly heart, and partly ſap, whether the operation of making the charcoal was diſcontinued as ſoon as the wood ceaſed to ſmoke, or protracted ſome time longer; and yet a difference in any one of theſe circumſtances, will ſenſibly influence the weight of the charcoal, procurable from a definite weight of wood.

The woods which I converted into charcoal were dry, and had been felled many years, their relative weights were taken with great exactneſs.

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* For. Satur. c. iv. p. 55.

Weight of a cubic foot of

Water	—	1000	avoir. ounces.
Box	—	950	——
Oak	—	892	——
Aſh	—	832	——
Mahogany	—	816	——
Walnut	—	790	——
Deal	—	615	——

Authors differ very much as to the weights which they have aſſigned to definite bulks of the ſame kind of wood. Thus, one eſtimates the weight of a cubic foot of dry box at 1030*; another at 1201 ounces †: one puts the weight of a cubic foot of dry oak at 925‡; another at 800 ounces ||. To the more obvious

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* Cotes Hydros. p. 73. † Ferguſon's Tab. p. 237. ‡ Cotes. || Emerſon's Mech. p. 132.

ſources of this diverſity, in the weights of equal bulks of the ſame kind of wood,—ſuch as the wood being green or dry, being cut from the boll or branch of a tree,—one may be added, which has not, I believe, been ſufficiently attended to —I mean the great loſs of weight which in certain circumſtances, the ſame piece of wood ſuſtains, by a ſimple expoſure to the atmoſphere, in the courſe of a few days.

From the middle of a branch of an oak tree, which had been felled in April, and expoſed without its bark, to the hot ſummer of 1779, I cut, Sept. 4, a round piece, about ſix inches in diameter, and three in thickneſs: Sept. 15, I cut from the heart of this piece of oak a ſmall ſlip, 3 inches in length, $\frac{1}{4}$ of an inch in thickneſs, and 79 grains in weight; at the ſame time, I cut a ſimilar ſlip from the ſap of the ſame piece, the weight of which alſo was 79 grains. theſe two pieces were put into the drawer of my ſtudy table, and being weighed again. Sept. 25, the heart of oak had loſt 8 grains, or near $\frac{1}{10}$ of its weight; the ſap had loſt 12 grains, or above $\frac{1}{7}$ of its weight. Now if the weights of ſeveral equal bulks of theſe woods had been taken on the 15th, and on the 25th of September, it is obvious, (notwithſtanding the contraction they might have ſuffered) that there would have been ſome difference in them though the woods themſelves appeared equally dry on both days.

This ſpeedy diminution of weight which wood undergoes by expoſure to the air, being a matter of ſome importance in an œconomical view, I will mention another experiment which I made on the ſubject. A piece of aſh cut March 17, 1780, from the middle of a large tree, which had been felled ſix weeks before, was accurately weighed; its weight was 317 grains, its length 3 inches, and its breadth 2. It was weighed again March 24, it had loſt in the courſe of 7 days 62 grains, or near $\frac{1}{5}$ of its weight. I weighed this ſame piece of wood on the 25th of Auguſt in the ſame year, but it had not loſt any thing of its weight, from the 24th of March to the 25th of Auguſt. The two pieces of oak, mentioned in the laſt experiment, were weighed alſo, on the 25th of Auguſt, 1780, they had neither of them loſt, in the courſe of eleven months, quite 1 grain; hence it appears; that the matter which is diſperſed from wood after it is cut, is ſoon evaporated: this matter probably conſiſts chiefly of water. The carriage of wood, eſpecially by land, is very expenſive: if an oak or an aſh tree was cut into boards, or ſcantlings, upon the ſpot where it is felled, there would be a ſaving of the carriage of one ton in ſix or ſeven, from the evaporation of the ſubſtance of the wood; to ſay nothing of chips and other refuſe parts.

It is well known that all wood becomes heavier than water, by having the air extracted from the pores, either by an air-pump, or by boiling it in water. The woods of which I have given the relative weights, were all of them rendered heavier than water, by a long continuance in cold water; for the heat of the water in which they were put, never exceeded 60 degrees. They ſunk in the water after they had been ſoaked in it for different lengths of time, but it required above 100 days ſoaking before the deal would ſink. After they had all lain in water for 110 days, I took them out, and let them dry by the gradual heat of the atmoſphere for above a month; I then weighed them, and found that box, oak, and aſh, had each of them loſt $\frac{1}{32}$ of the weight they had before they were put into the water; but that mahogany, walnut, and deal, had loſt only $\frac{1}{06}$ of their weight, This loſs of weight is occaſioned, partly by the eſcape of ſome portion of air, and partly by a diſſolution of ſome of the other principles of the woods; for the water, in which they were placed, had evidently acted upon them, its colour and conſiſtence being both changed. Moſt woods contain both a *gummy* and a *reſinous* part; and gums being ſoluble, and reſins not ſoluble in water, we can have no difficulty in apprehending the reaſon, why ſome ſorts of wood looſe a greater proportion of their weight, by being immerſed in water, and afterwards dried, than others. Since the ſame piece of wood has very different weights, when dry and when ſoaked with water; the covering carts, ploughs, and other huſbandry gear, uſually made of aſh, with a coarſe kind of paint which will keep out the rain, is a practice full as ſerviceable in leſſening the weight of the implement which is to be moved by the ſtrength of a man or horſe, as in preſerving the wood of which it is made from decay.

I took ſquare pieces of the woods before mentioned, each piece being 3 inches in length, and weighing exactly 96 grains, and expoſed them, when covered with ſand, in a crucible, to the action of the ſame fire, which was ſtrong enough to keep the crucible red hot, for three hours; they were, at the end of that time, all of them converted into perfect charcoals; the weights of the reſpective charcoals were taken, whilſt they were ſtill *warm*, from the operation, and are expreſſed in the following table:

Walnut	96 grns.	gave	25 grns.	of charcoal
Oak —	96	— —	22	——
Box —	96	— —	20	——
Mahogany	96	— —	20	——
Aſh —	96	— —	17	——
Deal —	96	— —	15	——

There is a good reaſon for remarking, that the charcoals were weighed whilſt they were warm, for in weighing them a few days afterwards, I found that they had all increaſed in weight in conſequence of *ſomething* which they had attracted from the atmoſphere; their weights then were —walnut 28 — oak 24 — box 23 —mahogany 24 — aſh 18 — deal 16 — grains.

The quantities of reſidue remaining from the diſtillation of 96 ounces of oak, box, and mahogany, were reſpectively 30, 26½, and 27½ ounces,

ces, which numbers are ſeverally larger than thoſe, expreſſing the quantities of charcoal obtainable from 96 parts of thoſe woods; this difference may proceed from the woods, employed in the two proceſſes, being of different qualities, or, more probably, from the heat in which the charcoal was made, being greater than that employed in the diſtillation; for the ſtronger the fire, the leſs is the quantity of charcoal, which a definite weight of wood will yield.

In making charcoal the workmen obſerve, that the pile of wood is ſenſibly diminiſhed in ſize by the operation; this proceeds from the ſhrinking of the wood. All the kinds of wood which I charred were diminiſhed in all their dimenſions, the mahogany, oak, and walnut, were the leaſt diminiſhed, and the box was the moſt diminiſhed; I thought it had loſt an eighth part of its length. This diminution not only depends upon the nature of the wood, but it is influenced by the ſtrength and continuance of the heat, that being moſt diminiſhed, which has ſuſtained the greateſt heat.

Though charcoal, from every ſort of wood, is incapable of being decompoſed, by the ſtrongeſt fires in cloſe veſſels, yet it is a compounded body, and may be decompoſed by being burned in the open air.

Van Helmont ſays, that 62 pounds of oak charcoal will, by burning, yield only 1 lb. of white aſhes. The other 61 pounds which are diſperſed into the air, he conſiders as a vapour of an elaſtic nature, which can neither be collected in veſſels, nor reduced into a viſible form. This vapour he called by a new name, *gas*[*].

Stahl is of opinion, that 10lbs. of charcoal made from porous woods, ſuch as fir and ſallow, will not, when burned with a very ſlow fire, yield above 1lb. of aſhes[†]; this quantity however, it muſt be remarked, is above ſix times the quantity aſſigned by Van Helmont to oak, which probably contains more aſhes in a definite weight of charcoal, than either fir or ſallow.

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[*] Hunc ſpiritum, incognitum hactenus, novo nomine gas, voco, qui nec vaſis cogi nec incorpus viſibile reduci poteſt. Van Hel. Op. om. p. 103. Some derive gas from the Dutch ghoaſt-ſpirit; others from the German gaſcht, a frothy ebullition.

[†] Stahlii Exper. Numero CCC. p. 17.

Geoffroy, from ſomewhat leſs than 34 ounces of the charcoal, remaining after the diſtillation of the heart of guaiacum, got near three ounces of white aſhes, by calcining the coal in an open fire for 12 hours. From near 23½ ounces of the coal, remaining from the diſtillation of the ſap of guaiacum, he got near 1½ ounce of aſhes. And 29½ ounces of the coal, from the bark of guaiacum, gave him 13½ ounces of white aſhes*.

Laſtly, M. Sage aſſures us that 100 pounds of charcoal will not, when burned, furniſh quite 2 ounces of aſhes †.

These accounts, it muſt be acknowknowledged, differ very much, as to the quantity of aſhes obtainable from a definite weight of charcoal; and the difference, I think, is much greater than what can wholly be attributed to the different textures of the ſeveral woods; a part of this diverſity may, probably, ariſe from a difference in the manner of burning the charcoal. When charcoal is burned in ſmall quantities, and in a ſlow fire, leſs of its ſubſtance will be diſperſed into the air, than when the quantity is larger, and the ſtream of air which ſupports the fire, is more rapid. This ſeems not improbable; but if the weight of the aſhes remaining from the burning of a definite weight of charcoal, be at all influenced by the degree of fire, it ſeems reaſonable to ſuppoſe, that what is driven off by the violence of the fire, is of the ſame earthy nature, as that which remains when the fire is more moderate; at leaſt it may be argued, that when charcoal is burned with a ſlow fire, ſome of its principles, its oily principle for inſtance, though it, probably, alſo contains a ſaline one, are more completely decompoſed, than when it is conſumed with a violent fire, and that the decompoſition of theſe principles, gives an additional quantity of earth or ſalt to the aſhes.

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* Geof. Mat. Med. or treatiſe on foreign vegeta. by Thickneſs. p. 112.

† Exper. ſur l'Alk. Vol. fluor. p. 27.

If there be any truth in this notion, we muſt not ſay, that the 61 pounds of matter which, according to Van Helmont, are diſperſed into the air from 62 pounds of charcoal, are wholly of an elaſtic nature; ſince they may conſiſt principally of an attenuated earth, which being driven off by the current of air, requiſite for the maintenance of the fire, remains for a time ſuſpended in the atmoſpherical air, without being in its own nature elaſtic. I would not be underſtood to ſay, that the whole of what is diſſipated, during the burning of the charcoal, is an attenuated earth, ſince it is certain, that the earth of the aſhes is not inflammable, and that charcoal contains ſomething which is inflammable; it is allowed alſo, that ſimple earth is inodorous, and it is well known, that charcoal, during its inflammation, diſperſes ſomething into the air, which has a ſtrong ſmell; this *ſomething* by which charcoal is rendered inflammable, and by which the air is infected with a particular ſmell, during the burning

ing of the charcoal, is called by moſt chemiſts the phlogiſton*. This

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* Phlogiſton is a conſtituent part of metallic ſubſtances, and it ſeems, when ſeparated from them, to be of an elaſtic nature. I diſtilled zinc with *ſtrong* acid of vitriol, and obtained a portion of ſulphur, produced, as it ſhould ſeem, by the acid's uniting itſelf with the phlogiſton of the zinc. No inflammable vapour was produced, till the ſulphur began to be ſublimed, then indeed, there eſcaped a vapour, compoſed, I think, of the attenuated parts of ſulphur, which upon the approach of a candle took fire. Another portion of zinc was diſtilled with *weak* acid of vitriol; before the zinc felt the heat of the fire, the inflammable air, ſeparable from zinc by a weak acid of vitriol, paſſed into the receiver, and being ſet on fire, burſt it with a great exploſion: another receiver was applied, and the diſtillation continued to dryneſs, but not a particle of ſulphur was produced, the phlogiſton neceſſary for its formation having, probably, been ſeparated from the zinc, by the violent action of the acid,

phlogiſton, whether it be an elaſtic inflammable fluid, or an unelaſtic earth of a particular kind, conſtitutes, probably, but a very ſmall portion of the weight of what is diſperſed into the air, from burning charcoal: we all know what a ſtrong ſmell may be diffuſed through a large room, from the ignited ſnuff of a candle, or from a very ſmall piece of charcoal, which has not been thoroughly burned; the vapours iſſuing from theſe ſubſtances are of an oily ſaline nature, and are viſible: the vapour of charcoal, though it is too ſubtle to be ſeen, may be of a nature ſomewhat ſimilar, and capable

acid, and conſumed at once by the inflammation. May it not from the compariſon of theſe experiments be conjectured, that the phlogiſton of metals is an elaſtic inflammable air?

ble of a very extenſive diffuſion through the air. An infant has been known ſuddenly to expire, from the ſmoke of a candle blown out under its noſe, and the vapour of charcoal is moſt dangerous, when the charcoal has not been thoroughly burnt.

It has been found by experiment, that the common atmoſpherical air is much altered in its properties, by being made to paſs through red hot charcoal, into the vacuum of an air pump; it then extinguiſhes the flame of a candle, and animals die in it*. a ſimilar change takes place, when charcoal is conſumed in an apartment, which has not a ſufficient ſupply of freſh air; the inſtances of perſons who have unhappily loſt their lives in ſuch air, are very common in all

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* Hauksbee's Exper. p. 287.

all countries, where much uſe is made of charcoal, but eſpecially in Ruſſia, where their apartments are heated by ovens, containing red hot charcoal*. The change which the atmoſpherical air undergoes, from the burning of charcoal, may proceed either from the air, having loſt ſome of its conſtituent parts in coming in contact with the burning charcoal, or from its having gained ſomething from the charcoal, or from its having done both at the ſame time; juſt as water which paſſes through a lump of ſalt or ſugar, loſes

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* Philoſ. Tranſ. 1779, p. 325—Where there is mention made of the Ruſſian method of recovering perſons who have been rendered ſenſeleſs by the vapour of the charcoal; it conſiſts in carrying the perſon into the open air, rubbing him with ſnow or cold water, and pouring water or milk down his throat.

a great part of the air it contains in its natural ſtate, and gains a portion of the ſalt, which becomes diſſolved in it, and upon both accounts ſuffers a change of its properties.

It is generally admitted, that charcoal and all other bodies, nitrous ones excepted, ceaſe to burn, as ſoon as they ceaſe to be ſupplied with freſh air, and the air has, chiefly on this account, been thought to communicate ſomething to the fire, by which the fire was maintained, and the air was conſumed. And this opinion has been confirmed by obſerving, that a definite quantity of air was much diminiſhed in bulk by bodies being burned in it. Thus, if 10 cubic inches of air be made to paſs through red hot charcoal, they will be reduced to nine, and there are means of making the diminution ſtill greater.

Dr. Hooke advances another hypotheſis; he allows air to be neceſſary to the ſupport of fire, but he thinks that it contributes to this ſupport, not by imparting any thing of its own ſubſtance to the fire, but by *diſſolving* the inflammable principle of bodies, as water diſſolves ſalts *: according to the former hypotheſis air is the *food*; according to this it is the *receptacle* or *ſolvent* of fire.

Dr. Prieſtly, to whoſe inventive genius and indefatigable induſtry the philoſophic world is peculiarly indebted for his inquiries into the nature of fictitious airs, has obſerved, that common air is diminiſhed one fifth by the fumes of burning charcoal; and this dimunition, he thinks is ſome how or other effected by the air being highly charged with the phlogiſton of the charcoal; and he obſerves, which agrees very well with Dr. Hooke's hypotheſis, that when any definite quantity of air is fully ſaturated with phlogiſton from charcoal, no heat that he had ever applied was able to produce any more effect upon the charcoal*.

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* Hooke's Micogr. p. 103. and Poſthum. Works p. 169. Juncker ſeems to have entertained a ſimilar notion—ingens aeris quantitas requiritur ad *diſſolvendas* et recipiendas ignitas illas et ultimo motu attenuatas particulas, unde niſi ſat aeris ſit extinguitur ignis. Junck. Conſ. Chem. Vol. I. p. 157.

Though common air is diminiſhed in bulk by the fumes of burning charcoal, and of other bodies in a ſtate of combuſtion, yet a bottle or a bladder filled with this diminiſhed air, weighs leſs than when it is filled with common air*, in the proportion of 183 to 185. That 5 cubic inches of common air, ſhould be reduced by the fumes of burning charcoal to 4 cubic inches, and that theſe 4 cubic inches of infected air, ſhould weigh leſs than 4 cubic inches of common air, cannot well be accounted for without admitting, that a part of the 5 cubic inches of atmoſpherical air, has been, by ſome means or other, taken away, at the ſame time that its bulk was reduced to 4 cubic inches.

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* Philoſ. Tranſ. 1772, p. 225—230.

Being deſirous of ſeeing, whether the property I had obſerved in charcoal, with reſpect to its weighing leſs when it was quite cold, than when it was warm from the fire in which it had been made, was a general property appertaining to all hot and cold charcoal, I weighed ſeveral pieces when they were cold, and again, when they were ſo hot as to be handled with difficulty, and found that they all loſt (they were of the ſame kind of wood) about 1 part in 12 of their weight, and that being left to cool in the open air, they regained what they had loſt in a few days. This acquiſition of weight was made moſt rapidly at firſt, a piece which weighed 240 grains when cold, was reduced by being heated, to 220 grains, and being left to cool, it gained 9 grains in 4 hours, and 15 grains in 8 hours. From the manner in which charcoal is made, it is probable that what remains adherent to the wood, is not greatly different from what is forced from it by the laſt degree of heat; now this conſiſts of an acid, and an oil rendered thick and pitchy by its union with an acid; may we not hence ſuppoſe, that it is a portion of fixed acid, which attracts the humidity of the air, or perhaps the air itſelf, when the charcoal is hot, and becomes ſaturated therewith, and that what was attracted, is again driven off when the charcoal is again heated; and thus the charcoal becomes again capable of exerting its attraction, and acquiring an encreaſe of weight? It is ſome confirmation of this hypotheſis, that charcoal when taken out of hot ſand, takes fire upon expoſure to the air, and for much the ſame reaſon, probably, that Homberg's pyrophorus takes fire in the open air*. Guaiacum contains a ſtronger acid than moſt kinds of wood, and Geoffroy has obſerved that "the coal of guaiacum being taken out of the retort, and expoſed to the air, even two or three days after the proceſs, takes fire immediately of its own accord;

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* Prieſt. Exp. and Ob. vol. II. p. 94.

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* Homberg's Pyrophorus is known to every ſchool-boy. It is made by calcining together for a proper time, and in proper quantities, either alum or any ſalt containing the vitriolic acid, with honey, ſugar, flour, or any animal, or vegetable ſubſtance, capable of being reduced to a coal. Part of the vitriolic acid being uncombined with the phlogiſton of the coal, and being in a dry condenſed ſtate, attracts the humidity of the atmoſphere, and generates ſuch a degree of heat by its mixture with water, as is ſufficient to inflame the other part of the pyrophorus. Pyrophori may be made without the vitriolic acid, but ſome acid probably enters into their compoſition.

provided, that when the diſtillation is over, the neck of the retort be carefully ſtopped, and the veſſels and furnace be left to cool of themſelves"*.

This property of increaſing in weight by expoſure to the air, belongs to the hot coal of pitcoal, as well as to that of wood; I took ſome red hod cinders, and weighing them in that ſtate, left them to cool; in 12 hours they had gained one 75th part in weight, and in 4 days they had gained one thirtieth of their weight. Some coak which had been burned with a ſtrong fire, gained much leſs than the cinders.

It has been obſerved in another place, that charcoal may be decompoſed, by being diſtilled with the acid of vitriol*; this acid robs the charcoal of its inflammable principle, and reduces it to an earth: no other menſtruum ſeems to have any action upon it. What alteration might be produced in charcoal, by quenching it when red hot, in various menſtruums, or by boiling it in them, or by keeping it immerſed in them, when cold, for a long time, or by other leſs obvious proceſſes, it does not fall within my deſign to inquire.

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* Treatiſe on foreign vege. p. 111.

Animals and vegetables are ſoon reduced by putrefaction to an earth; many ſorts of ſtones and metallic ſubſtances are crumbled into duſt by the action of air and water; but charcoal remains unchanged for ages, whether it be expoſed to the air, or immerſed in water, or buried in the earth. The beams of the theatre at *Herculaneum* were converted into charcoal by the *Lava*, which overflowed that city, and during the lapſe of above ſeventeen centuries the charcoal has remained as entire as if it had been formed but yeſterday, and it will probably continue ſo to the end of the world. This incorruptibility, as it may be called, of charcoal has been known in the moſt diſtant ages; for it has been obſerved that the famous temple of Epheſus was built upon wooden piles which had been charred on the outſide. The cuſtom of charring the ends of poſts which are to be fixed in the earth is very common, and I have often wondered that the ſame cuſtom has not prevailed with reſpect to the wood uſed in mines and ſubterraneous drains. The timbers which ſupport, in many places, the roof of the ſoughs through which there is a current of water, are waſted away in a few years, that part of them eſpecially which is expoſed to the alternatives of moiſture and dryneſs by the riſing and falling of the water is ſoon rotted, and this part one would think would be charred with great advantage.

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* Vol. I. p. 175.

ESSAY II.

OF THE QUANTITY OF WATER EVAPORATED FROM THE SURFACE OF THE EARTH IN HOT WEATHER.

THERE are many operations conſtantly carrying on by natural means, which, though they eſcape the ordinary obſervation of our ſenſes, ſufficiently excite our aſtoniſhment when once diſcovered. The vaſt quantity of a particular kind of air, with which the atmoſphere is daily impregnated, from the combuſtion of all ſorts of fuel, is one inſtance of this kind; and the water which is raiſed into the atmoſphere from the ſurface of the earth, is another. Who would have conjectured that an acre of ground, even after having been parched by the heat of the ſun in ſummer, diſperſed into the air above 1600 gallons of water in the ſpace of twelve of the hotteſt hours of the day? No vapour is ſeen to aſcend, and we little ſuppoſe that in the hotteſt part of the day, more uſually does aſcend than in any other. The experiment from which I draw this concluſion, is ſo eaſy to be made, that every one may ſatisfy himſelf of the truth of it. On the 2d of June, 1779, when the ſun ſhone bright and hot, I put a large drinking glaſs, with its mouth downwards, upon a graſs-plat which was mown cloſe; there had been no rain for above a month, and the graſs was become brown; in leſs than two minutes the inſide of the glaſs was clouded with a vapour, and in half an hour drops of water began to trickle down its inſide, in various places. This experiment was repeated ſeveral times with the ſame ſucceſs.

That I might accurately eſtimate the quantity, thus raiſed, in any certain portion of time, I meaſured the area of the mouth of the glaſs, and found it to be 20 ſquare inches: there are 1296 ſquare inches in a ſquare yard, and 4840 ſquare yards in a ſtatute acre; hence, if we can find the means of meaſuring the quantity of vapour raiſed from 20 ſquare inches of earth, ſuppoſe in one quarter of an hour, it will be an eaſy matter to calculate the quantity which would be raiſed with the ſame degree of heat, from an acre in 12 hours. The method I took to meaſure the quantity of vapour, was not perhaps the moſt accurate which might be thought of, but it was ſimple and eaſy to be practiſed: when the glaſs had ſtood on the graſs-plat one quarter of an hour, and had collected a quantity of vapour, I wiped its inſide with a piece of muſlin, the weight of which had been previouſly taken; as ſoon as the glaſs was wiped dry, the muſlin was weighed again, its increaſe of weight ſhewed the quantity of vapour which had been collected. The medium increaſe of weight, from ſeveral experiments made on the ſame day, between 12 and 3 o'clock, was 6 grains collected in one quarter of an hour, from 20 ſquare inches of earth. If the reader takes the trouble to make the calculation, he will find that above 1600 gallons, reckoning 8 pints to a gallon, and eſtimating the weight of a pint of water at one pound avoirdupoiſe, or 7000 grains troy weight, would be raiſed, at the rate here mentioned, from an acre of ground in 24 hours.

It may eaſily be conceived that the quantity thus elevated, will be greater when the ground has been well ſoaked with rain, provided the heat be the ſame; I did not happen to mark the heat of the ground when I made the forementioned experiments; the two following are more circumſtantial: the ground had been wetted the day before I made them by a thunder ſhower, the heat of the earth at the time of making them, eſtimated by a thermometer laid on the graſs, was 96 degrees; one experiment gave 1973 gallons from an acre in 12 hours, the other gave 1905. Another experiment made when there had been no rain for a week, and the heat of the earth was 110 degrees, gave after the rate of 2800 gallons from an acre in 12 hours; the earth was hotter than the air, as it was expoſed to the reflection of the ſun's rays from a brick wall.

The heat in *Bengal* in the ſummer months is variable, in the ſhade from 98 to 120 degrees,* and in the ſun it probably does not fall ſhort of

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* Philoſ. Tranſ. 1767. page 218, and for the year 1775. p. 20.

140 degrees; hence, after the earth has been well drenched by the overflowing of the *Ganges*, immenſe quantities of vapours muſt be daily raiſed, to the amount, perhaps, of five or ſix thouſand gallons from an acre, in twenty-four hours. The rainy ſeaſon in Bengal laſts from the beginning of June to the middle of October, all this interval is conſidered as an unhealthy time, but eſpecially the latter part of it; for then the earth begins to grow dry, the ſlime left upon its ſurface, conſiſting of decayed vegetables and other putreſcent bodies, begins to corrupt, and the ſun by its violent and continued action raiſes up into the air, not a pure water, but water impregnated with putrid particles of all kinds.

Whether a merely moiſt ſituation

be unwholeſome may be much queſtioned, but that moiſture ariſing from earth or water in a ſtate of putrefaction is ſo, cannot well be doubted. The overflowing of the *Nile* puts a ſtop to the plague in *Egypt*, inſomuch, probably, as it puts a ſtop to the putrefaction of the canals of *Grand Cairo* and other places. Agues and putrid fevers are much more frequent in the fens of *Cambridgeſhire* and *Lincolnſhire* in very dry, than in wet years; the *Iriſh*, who annually come to reap the harveſt in the fens of Cambridgeſhire, have been ſo ſenſible of the difference, that for the three or four years laſt paſt, which have been very dry, they have entered upon their taſk with great reluctance and apprehenſion of what they call the *Fen-ſhake*. The

States of *Holland*, in the year 1748, laid the country around *Breda* under water, and ordered the water to be kept up till the winter, in order to ſtop a ſickneſs which had ariſen from the moiſt and putrid exhalations of half-drained grounds.* The *Arabs* are ſaid to take a horrid kind of vengeance when they think themſelves injured by the *Turks* at *Baſſora*; they contrive to overflow the adjoining country: a peſtilential fever begins to ſhew itſelf as the land begins to grow dry by the evaporation of the water, and it rages with ſuch violence as to carry off many thouſands of the inhabitants of that city.†

The nature of the ſoil muſt have a great influence on the health of the people who inhabit it, ſo far as that is dependent on the moiſture or dryneſs of the air. There is, probably, as much water raiſed into the air, in a hot day, from an acre of ground in the fens of *Cambridgeſhire*, as is raiſed in two or three days from an equal ſurface in the ſandy parts of *Norfolk* and *Suffolk*, Not but the moſt ſandy country may have a very moiſt atmoſphere, when water happens to be found near the ſurface; for the heat of the ſun will penetrate through the ſand, and raiſe the water in vapour, which will find an eaſier paſſage through the ſand than it would do through a leſs open ſoil. Thus the ſoil in ſome parts of *Dutch Brabant* is a barren ſand, but water is every where to be met with at the depth of two or three feet, and in proportion to its diſtance from the ſurface the inhabitants are free from diſeaſes.*

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* Sir J. Pringle's Diſ. of the Army, p. 63.

† Philoſ. Tranſ. 1778, p. 215.

Vegetation muſt be greatly influenced by the quantity of water which is raiſed from the earth; ſome ſoils retain humidity much longer than others, and one great uſe of marles and other manures, is to render the ſoil on which they are put leſs liable to be deprived of its moiſture by the heat of ſummer. The water in aſcending from the boſom of the earth, moiſtens the roots, and in being diſſolved in the air, it affords nutriment to the branches of vegetables; but as vegetation may be injured either by a defect, or an exceſs of moiſture, and as different plants require different quantities of it, for attaining their utmoſt perfection, it merits the attentive obſervation of the farmer to ſuit his plants and his manures to the nature of the ſoil. There are many ſandy and limeſtone ſoils, which are covered almoſt with flints or limeſtone pebbles; the crop of corn would, probably, be leſs, if theſe ſtones were removed; for they are ſerviceable, not only in ſheltering the firſt germs of the plant from cutting winds, but they impede the eſcape of moiſture from the earth; the aſcending vapour ſtrikes upon that ſurface of the ſtone which is contiguous to the earth, and is thereby condenſed, and thus its further aſcent is for a time, at leaſt, prevented.

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* Diſeaſ. of the Army, p. 62.

Upon the ſame graſs-plat, and contiguous to the glaſs uſed in the experiments, I placed a ſilver cup, with its mouth downwards, of a ſhape ſimilar to that of the glaſs, and nearly of the ſame dimenſions; but I could never obſerve that its inſide had collected the leaſt particle of vapour, though I frequently let it ſtand on the graſs for half an hour, or more.

By means of a little bee's wax, I faſtened an half crown very near, but not quite contiguous, to the ſide of the glaſs, and ſetting the glaſs, with its mouth downwards, on the graſs, it preſently became covered with vapour, except that part of it which was near to the half crown. Not only the half crown itſelf was free from vapour, but it had hindered any from ſettling on the glaſs which was near it, for there was a little ring of glaſs ſurrounding the half crown to the diſtance of $\frac{1}{4}$ of an inch which was quite dry, as well as that part of the glaſs which was immediately under the half crown; it ſeemed as if the ſilver had repelled the water to that diſtance. A large red wafer had the ſame effect as the half crown, it was neither wetted itſelf nor was the ring of glaſs contiguous to it wetted. A circle of white paper produced the ſame effect, ſo did ſeveral other ſubſtances, which it would be tedious to enumerate.

Theſe phenomena, reſpecting the different diſpoſitions of different bodies to attract the *riſing* vapour, are ſimilar to what others have taken notice of concerning the *falling* of dew, and are, probably, to be explained upon the ſame principles, whatever they may be. Muſchenbroek placed on the leaden terras of the Obſervatory at Utrecht veſſels of glaſs, china, varniſhed wood, poliſhed braſs, and pewter; he found that in the courſe of a night the glaſs, china, and varniſhed wood, had collected a great abundance of dew, but that not a drop had fallen on any of the poliſhed metals *. M. du Fay expoſed to the air, when the dew was falling, two large funnels, one made of glaſs the other of poliſhed pewter; the necks of the funnels being inſerted into veſſels proper to retain any moiſture which might be collected by them; he ſometimes found in the morning that the veſſel under the glaſs funnel contained an ounce or more of water,

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* Introd. ad Philoſ. Nat. Tom. 2. p. 990.

but he never obſerved ſo much as a drop in the other*.

A great part of the water which is raiſed into the air from the perſpiration of the earth during a hot day, deſcends down again upon its ſurface in the courſe of the night; and this is the reaſon that the dews are the greateſt in the hotteſt weather, and in the hotteſt climates. The earth retains the heat it receives in conſequence of the ſun's action longer than the air does; water, moreover, is evaporable in all degrees of heat; hence water may continue to riſe from the earth, when the air, being cooled by the abſence of the ſun, is no longer able to ſuſtain what is thus raiſed, or to retain what it had taken up during the day time, and a dew from theſe different cauſes may, under certain circumſtances, be found both to riſe and fall during the whole night.

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* Hiſt. de l'Acad. des Scien. 1749.

Egypt, at one ſeaſon of the year, is ſo parched up by the heat, that the ſurface of the ground becomes quite rugged with fiſſures; at this time the dew, proceeding from the vapour exhaled from the earth, is very plentiful, and by its plenty prevents the total deſtruction of the country. "This dew is particularly ſerviceable to the trees, which would otherwiſe never be able to reſiſt the heat; but with this aſſiſtance they thrive very well, bloſſom and ripen their fruit. Therefore, the upper parts of the Egyptian trees, at one time of the year, do the office of roots, attracting nouriſhment by their abſorbent veſſels, the leaves, from the moiſt air."*

The quantity of water which was condenſed on the inſide of the glaſs, I found to be accurately proportionable to the time during which it ſtood on the graſs; for in one experiment 6 grains were collected in 10 minutes, and in another 15 grains were collected in 25 minutes; now the proportion of 6 to 10 is the ſame as that of 15 to 25.

In order to ſee whether the copious vapour collected by the glaſs was owing to the natural perſpiration of the graſs, or to a kind of mechanical diſtillation from the body of the earth, I put the glaſs upon a footpath which was dry, and had no graſs growing upon it, the vapour roſe from the footpath as well as from the graſs, but not ſo abundantly.

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* Haſſelquiſt's Voy. p. 455.

From what has been advanced, it may, probably, be juſtly inferred, that the air contiguous to, or not far removed from, the ſurface of the earth, whether that ſurface be plain or mountainous, barren, or covered with vegetables, will be much more loaded with the vapour which ariſes conſtantly from the earth, than that which is at the diſtance of even a few yards from the ſurface. This point may be illuſtrated by the following hypotheſis——Suppoſe the earth to be a globe of rock ſalt, and to be covered with water to the height of a mile; imagine the water to be divided into four ſpherical ſhells, each $\frac{1}{4}$ of a mile in thickneſs. Now the firſt ſhell, which is ſuppoſed to be contiguous to the ſurface of the ſalt, would ſoon ſaturate itſelf with the ſalt, and becoming thereby heavier than the water at a greater diſtance, it would not, by the ordinary motion of the winds and tides, ſoon mix itſelf with the whole maſs of water; but it would contain far more ſalt in ſolution than the ſecond ſhell, and the ſecond would contain more than the third, and the third more than the fourth. Let us further ſuppoſe the ſalt contained in the whole of the water to be precipitated, and the precipitation to begin from the ſhell fartheſt removed from the ſurface of the earth; it is evident, that the quantity of the precipitate will increaſe, not ſimply with the increaſe of ſpace through which it has deſcended, but in a much higher proportion, inaſmuch as the laſt ſhell, through which it deſcends, may be ſuppoſed to contain three or four times as much ſalt as the uppermoſt. In like manner, it ſeems reaſonable to ſuppoſe that the air which is near the ſurface of the earth will be greatly more charged with water, which it diſſolves as water diſſolves ſalt, than that which is ſituated at the diſtance of even a few yards from the ſurface.

Dr. Heberden was the firſt perſon who took notice, that a much larger quantity of rain falls into a rain-gage ſituated near the ſurface of the earth, than into one of the ſame dimenſions ſituated a few yards above it*; and he thinks that this difference is to be explained from ſome unknown property of electricity. The fact is placed beyond controverſy, by experiments which have been made at various places; at Liverpool in particular it has been obſerved, that " a veſſel ſtanding on the ground in a ſpacious garden, received *double* the quantity of rain which fell into another veſſel of equal dimenſions placed near the ſame ſpot, but eighteen yards higher"†. I am far from thinking that the foregoing obſervations, relative to the quantities of water contained in equal bulks of air at different heights from the ſurface of the earth, contain a ſatisfactory explanation of this phenomenon; yet it may be remarked, that rain gages placed at equal diſtances from the ſurface of the earth, collected nearly equal quantities of rain, though one of them was ſituated on a plain, and the other on a mountain 450 yards in height above the plain*: this obſervation is ſome confirmation of the hypotheſis which has been mentioned, as on that ſuppoſition it follows, that the air at the ſame diſtance from the ſurface of the earth, is equally impregnated with water, other circumſtances being the ſame, and therefore equal quantities of rain *ought* to be collected by veſſels placed at equal diſtances from the ſurface

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* Phil. Tranſ. 1769. p. 361.

† See an ingenious eſſay on the ſubject, by Dr. Percival, who has explained the phenomenon from the known principles of electricity. Eſſays by Dr. Perci. p. 112.

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* Philoſ. Tranſ. 1772, p. 294.

face of the earth; though according to the ſame ſuppoſition, a much larger quantity *ought* to be collected by a veſſel placed on the ſurface, than by one placed a few yards above it. Thus this hypotheſis, admitting its truth, (which future experiments will perhaps eſtabliſh) ſeems as if it was ſufficient for explaining the phenomenon; I would be underſtood however to mention it with much diffidence, and was I as much ſkilled in electricity, as the very worthy and ingenious perſon, who firſt noticed the fact, is in every branch of natural philoſophy, I might probably have ſeen reaſon not to mention it at all.

ESSAY III.

OF WATER DISSOLVED IN AIR.

WE have ſeen, in the preceding Eſſay, that large quantities of water are raiſed from the earth in the hotteſt weather: the water, which is thus elevated, is no more viſible in the air, than a piece of ſugar is viſible in the water wherein it happens to be diſſolved, nor is the tranſparency of the air injured by the water it has received from the earth, and thereſore we conclude, that the water is not merely *mixed* with the air, but really *diſſolved* in it; a perfect tranſparency of the fluid, in which any body is diſſolved, being eſteemed the moſt unequivocal mark of its ſolution.

The cauſe of the aſcent, ſuſpenſion, and deſcent of vapours, is not yet fully determined; many think that electricity is the principal agent in producing theſe phenomena*; whilſt others are of opinion, that water is raiſed and ſuſpended in the air, much after the ſame manner in which ſalts are raiſed and ſuſpended in water; and it muſt be owned that this opinion (which future experience may ſhew not to be wholly inconſiſtent with the other) has a great appearance of probability.

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* Philoſ. Tranſ. 1755. p. 124.—Electricitas, vapores in aërem extollit, in aëre ſuſpendit, et ex aëre in tellurem depluit. Prof. Bavers Exp. de Elec. Theo. p. 106.

Salts, in general, are more ſpeedily diſſolved in warm water than in cold; and water, in like manner, is more ſpeedily diſſolved in warm air than in cold. We have a ſenſible proof of this, in the exhalation of dew, it being much ſooner dried up in places expoſed to the direct rays of the ſun, than in the ſhade; becauſe the air in the ſhade, being ſome degrees colder than that in the ſun, is not able to diſſolve the ſame quantity of water in the ſame time.

When water is ſaturated with any kind of ſalt in a definite degree of heat, then will it retain the ſalt as long as it retains its heat; but if the heat be leſſened, the tranſparency of the ſolution will be deſtroyed, a part of the ſalt will become viſible, and fall to the bottom, in conſequence of its ſuperior weight; what falls to the bottom will be rediſſolved, as ſoon as the water regains its heat. It is obvious that the quantity of the ſalt, which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the ſolution is ſaturated, and partly on the degree of cold to which the ſolution is reduced. Thus water of 80 degrees when ſaturated with ſalt, contains more ſalt than it would do if it had only 70 degrees of heat, and in being cooled to 50 degrees, the precipitation of ſalt will be greater in the firſt inſtance, than in the ſecond; though it might, probably, be the ſame, if the ſolution of 80 degrees was cooled only to 60, and that of 70 to 50. Something very analogous to all this may be obſerved, with reſpect to the ſolution of water in air. In miſty weather, we frequently ſee the miſt of the morning intirely vaniſhing towards the middle of the day, and coming on again towards the evening; the reaſon of which ſeems to be, that the air being warmed by the approach of the ſun to the meridian, is able to diſſolve the morning miſt, but as the air grows colder again towards the evening, the water which had been perfectly diſſolved by the midday heat begins to be precipitated, the tranſparency of the air is deſtroyed, and an evening miſt is formed.

This phenomenon has been obſerved to prevail, in the coldeſt atmoſphere that has ever yet been taken notice of, on the ſurface of the globe; for in January 1735, when the cold in *Siberia* was equal to 157 degrees below the freezing point in Farenheit's thermometer, the lower region of the air was obſcured by a perpetual cloud, which was very thick in the morning, thinner towards noon, and thicker again at night*.

Miſts and dew will, generally ſpeaking, be the greateſt when the difference between the heat of the air, in the day time, and at night, is the greateſt, becauſe the hotter the day, the greater is the quantity of water which is diſſolved; and the colder the night, the greater will be the quantity which is precipitated. It often happens that there is no miſt obſervable towards the cloſe of the day, this may be occaſioned, either by there being little difference in the heat of the air at noon, and at night; or, though that difference be conſiderable, yet the air may chance not to be ſaturated with water, and in that caſe it may, even in the night, be warm enough to retain all the water it had diſſolved in the day time. In cold weather the breath of animals becomes viſible, becauſe the air is not warm enough to diſſolve the moiſture which is exhaled from the lungs*.

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* Novi Commen. Petrop. Tom. vi. p. 429.

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* The breath is viſible if the temperature of the air be colder than 61 degrees. Caval. on air p. 400. The degree of cold in which it is viſible, depends partly on the humidity, or dryneſs of the air.

It is not unuſual for a river in winter time, to be much warmer than the air, hence, the vapour which riſes from the river is condenſed, the air not being able to diſſolve it, and a cloud or miſt of ſmall elevation, is ſeen to accompany the river in its courſe; this appearance ceaſes, as ſoon as the river is frozen, becauſe the ice, though it be ſubject to evaporation, yet it does not yield ſo much vapour as water does*.

A cubic inch of rock ſalt, nitre, or any other kind of ſalt, is much longer in being diſſolved, when it is in a compact ſtate, than when it is reduced into a fine powder, becauſe the ſalt, when in the form of a powder,

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* Angara fluvius nocte glacie confiſtit, quo facto *nebula* illa perpetua, huc uſque ex fluvio hoc evecta ceſſavit. Novi Comp. Petrop. Vol. VI. p. 436.

der, has a much larger ſurface expoſed to the action of the water, than if it was in one ſolid lump. In like manner, the air will diſſolve any definite quantity of water ſooner, when the ſurface of the water is increaſed by its being in the form of a vapour, than it would do if the water was either in the form of ice, or in its ordinary fluid ſtate. The ſmoke of a chimney conſiſts principally of water, in the ſtate of vapour, and it is really aſtoniſhing, to ſee how quickly, in particular ſtates of the atmoſphere, it is diſſolved in the air.

It has been remarked, that the ſmoke of mount *Veſuvius* is much more ſtrong and viſible in rainy, than in fair weather;* if this phenomenon

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* Lett. ſur. La Mineral. par. M. Ferber. p. 188.

nomenon does not proceed from the greater quantity of water, which is raiſed from the mountain in wet, than in dry weather; it may be accounted for, from the greater facility with which aqueous vapours are diſſolved in a dry ſerene air, than in one which is ſo ſaturated with water, that it can diſſolve no more; which is the caſe, in general, of air, which parts with its water, in the form of rain or miſt.

In riding upon wet ſand in a hot day, a kind of tremulous motion in the air, to the height of a foot or more above the ſand, may be obſerved; this appearance may proceed from hence, that the water in riſing from the ſand, is not immediately diſſolved in the air. A ſimilar appearance may often be obſerved on land, eſpecially in corn fields towards autumn; the water which is exhaled from the ſtanding corn, not mixing itſelf at once, ſo effectually with the air, as to conſtitute with it an apparently homogeneous fluid. Something of the ſame kind happens, when either ſaline ſolutions, wines, or vinous ſpirits of any kind, are poured into a glaſs of water, the compound fluid muſt be agitated, or the mixture will not at firſt be uniform.

The quantity of water contained in the air, even in the drieſt weather, is very conſiderable. We may be ſaid to walk in an ocean; the water indeed of this ocean, does not ordinarily, become the object of our ſenſes, we cannot ſee it, nor, whilſt it continues diſſolved in the air, do we feel that it wets us, but it is ſtill water, though it be neither tangible nor viſible; juſt as ſugar, when diſſolved in water, is ſtill ſugar, though we can neither ſee it nor feel it.

Some philoſophers have doubted, whether the weight of the air, may not chiefly be attributed to the water which is conſtantly ſuſpended in it *. But whether this conjecture be admitted or not, the power which the air has of keeping a great quantity of water diſſolved in it, may very properly be applied to the illuſtration of that text, in which it is ſaid, *God divided the waters which were under the firmament, from the waters which were above the firmament* †, without having recourſe with *Epiſcopius,*

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* Boerh. Chem. Vol. I. p. 461.

† Gen. i. 7.

copius, to the very unphiloſophical ſuppoſition of the blue ſky being a ſolid ſubſtance compoſed of congealed water*. Some are puzzled to find water enough to form an univerſal deluge; to aſſiſt their endeavours it may be remarked, that was it all precipitated which is diſſolved in the air, it might probably be ſufficient to cover the ſurface of the whole earth, to the depth of above thirty feet.

The air not only diſſolves water, but various other vapours, which conſiſt

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* Extima ſive ſuprema hujus aëris regio attingit fornicem illum cæruleum, in quo poſtea die quarta ſtellæ fixæ collocatæ fuerunt; qui fornix cæruleus mihi eſſe videtur aquarum in altum elevatarum, et cryſtalli im morem ſeu condenſatarum, ſeu conglaciatarum, cæruleoque colore radiantium, compages. Epis. Ins. Theol. Lib. iv. c. 3.

ſiſt partly of water, and partly of volatile ſalts and oils. All vegetables, whether aromatic or not, are found to perſpire very greatly, and the matter which they perſpire, could it be condenſed, would, probably, be ſo far different from pure water, as to have both a taſte and ſmell. The matter perſpired by animals, without ſweating, conſiſts principally of water, but the water is ſtrongly impregnated with odorous particles. It has been ſaid of *Baron Haller*, that he could ſmell the perſpiration of old people, at the diſtance of ten yards; this is by no means incredible, for the human body is conſtantly enveloped in an inviſible cloud, ariſing from the great quantity of matter which is inſenſibly perſpired. *Sanctorius* eſtimates the *ſenſible* excretions of a perſon who eats and drinks 8 lbs of food in 24 hours, at 3 lbs, and the *inſenſible* perſpiration at 5 lbs; but if we ſuppoſe the inſenſible perſpiration in this climate (which is colder than that of *Venice*, where he made his experiments) to amount only to one half of our food, we cannot but conclude, that it muſt form a great cloud around us; for 4 lbs of matter converted into a vapour as heavy as air, would occupy a great ſpace, amounting to above 50 cubic feet. The heat of the human body is generally between 90 and 100 degrees, this degree of heat is ſufficient to raiſe from it, by a kind of diſtillation, a copious vapour, which would become viſible, if the heat was increaſed; I remember having been greatly heated and fatigued in aſcending the ladders from the bottom of the copper mine at *Ecton*; when I got to the top I obſerved, by the light of a candle, a thick vapour reeking from the body, and viſible around it, to the diſtance of a foot or more.

The diſpoſition of the air for diſſolving either pure water, or the matter perſpired by vegetables, or animals, is very various, depending chiefly on its *denſity*, *heat*, and *dryneſs*. The power which dogs have of ſcenting the animal they are in purſuit of, muſt be much affected by this diſpoſition of the air; for the air through which the animal has paſſed, is impregnated with the matter perſpired from its body; and this matter may in one ſtate of the air be ſo ſpeedily diſſolved, and ſo much as it were diluted with air, as to make either no impreſſion, or a very ſlight one, on the olfactory nerves of the dog; whilſt in another, it may make a very ſenſible one. And if we ſuppoſe the perſpirable matter not to conſiſt chiefly of water*, but of ſuch particles as are thrown off by perfumes, without their loſing ſenſibly of their weight, ſtill it will be true, that the ſtate of the air muſt have a great influence in rendering them ſenſible; ſince it has been found, that on the tops of very high mountains, where the ſtate of the air is very different from what it is in the valleys below, the moſt odorous bodies loſe either intirely, or in a great degree, their powers of exciting a ſmell.—The exiſtence of water in air is made apparent various ways.

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* If the whole body of a naked man, except his mouth and noſtrils, was ſhut up in a glaſs caſe, ſo that no air could enter, the matter of the *inſenſible* perſpiration, would, probably, be condenſed, and ſtand as dew on the inſide of the glaſs; and I apprehend it would not differ much from the matter of the *ſenſible* perſpiration, or ſweat. But if any one be diſpoſed to conſider the inſenſible perſpiration, as an uncondenſable fluid, or a kind

If a bottle of wine be fetched out of a cool cellar, in the hotteſt and drieſt day in ſummer, its ſurface will preſently be covered with a thick vapour, which, when taſted, appears to

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kind of air ſimilar to that which ariſes from vegetable fluids, in a ſtate of fermentation, (the heat of fermenting wort, being much the ſame as that of an animal body) ſtill its mixture with the atmoſpherical air, muſt depend very much on the weight, humidity, and other properties of that air.

to be pure water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for glaſs is impervious to water, and the bottle remains full, and when wiped dry, it is found to weigh as much as when taken out of the cellar. The ſame appearance is obſervable on the outſide of a ſilver, or other veſſel in which iced water is put in ſummer time; and it is certain, that the water which is condenſed on the ſurface of the veſſel, does not proceed merely from the moiſture exhaled by the breathing of the people in the room, where this appearance is moſt generally noticed, becauſe the ſame effect will take place, if the veſſel be put in the open air. Water which is cooled by the ſolution of any ſalt, or even ſpring water, which happens to be a few degrees colder than the air, produces a ſimilar condenſaſion of vapour on the outſide of the veſſel in which it is contained. Theſe and other appearances of the ſame kind, are to be explained on the ſame principle. Warm air is able to retain more water in ſolution than cold air can; when therefore warm air becomes contiguous to the outward ſurface of a veſſel, containing cold liquor, it is preſently cooled to a certain degree, and in being cooled, it is forced to part with ſome of the water which it had diſſolved, and this water, ceaſing to be ſuſpended by the air, attaches itſelf to the ſurface of the cold veſſel.

The more ancient philoſophers,

not ſuſpecting that water might be diſſolved in air, were of opinion that the moiſture which they obſerved adhering to the outſides of veſſels, which had been cooled by having ſnow put into them, proceeded from a tranſmutation of air into water*. But there ſeems to be no more reaſon for this ſuppoſition, than there would be for ſaying, that water was changed into ſaltpetre, from obſerving that water which had diſſolved as much ſaltpetre as it could, in a certain degree of heat, depoſited a part of it, when that degree of heat was leſſened.

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* Naturæ myſtas arcano modo, ſed facili *aërem in aquam* mediis caloribus cogere docebit abjecta hæc nix, ſi vitro conicæ figuræ, intra tripodem, apice deorſum vergente, ſuſpenſo indatur nivis vel glaciei fruſtum. Quippe ſubjecto vaſculo excipiuntur, exteriore vitri frigiditate collectæ, et laterum declivitate manantes aquæ guttæ. Bartholinus de figura Nivis p. 3. See alſo Boyle's Works, Vol. II. p. 297.

Another method of proving the exiſtence of water in the cleareſt air, is, to obſerve the increaſe of weight, which certain bodies acquire by expoſure to the *open* air. I put upon a plate 8 ounces of ſalt of tartar, which had been well dried on a hot iron; the day was without a cloud, and the barometer ſtood at 30 inches; in the ſpace of three hours, from 11 to 2 o'clock in the afternoon, the ſalt had increaſed in weight two ounces; in the courſe of a few days its weight was increaſed to twenty ounces, it was then quite fluid, and being diſtilled it yielded a pure water equal in weight nearly to the increaſe it had acquired from the air, and therefore it is rightly inferred, that water was the ſubſtance which it had attracted from the air.

Strong acid of vitriol is another body which very powerfully attracts humidity from the air. An ounce of this acid has been obſerved to gain, in 12 months, above ſix times its own weight.* The power of the acid to attract water from the air, depends upon its ſtrength, for it may be ſo far diluted, that inſtead of attracting any more water from the air, it will, by evaporation loſe a part of that which it had acquired; when it is in this ſtate, its weight varies with the dryneſs or moiſtneſs of the atmoſphere, and it becomes, when accurately balanced in a good pair of ſcales, no bad kind of an hygrometer.

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* Newm. Chem. by Lewis, p. 161.

grometer. The time in which any definite quantity of acid acquires its greateſt weight from the air, depends partly upon the quantity of water which is diſſolved in the air, and partly upon the ſurface of the acid which is expoſed to the air, it having been aſcertained by experiment, that the quantity attracted from the air, in a definite portion of time, is greater as the ſurface is greater. Hence, inſtead of a twelve months expoſure to the air being requiſite to make one ounce of acid of vitriol acquire ſix ounces of water, it might poſſibly acquire that weight in a few minutes, if its ſurface was enlarged in a due proportion.

Onions and other bulbous roots, when hung up in a room ſheltered from rain and dew, are obſerved to germinate, and to acquire a great increaſe of bulk, and it might thence have been ſuſpected, that they attracted much water from the air, and were increaſed in weight. But though they may increaſe in bulk, they are found to decreaſe in weight; the root itſelf in becoming rotten, ſupplies nutriment to the germinating plant; and if it imbibes any thing from the air, it loſes that and more by perſpiration. An onion on the 26th of January, when it had ſcarce begun to ſhew any ſigns of vegetation, weighed 296 grains; on the 16th of the following May, after having put forth ſeveral ſtems in the open air, it weighed only 145 grains.*

The increaſe of weight which the human

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* Novi Com. Petrop. Tom. 2. p. 225.

human body, in many caſes, experiences from the water which the pores of the body ſuck in from the air. is another very ſenſible proof of the great quantity of water which is conſtantly diſſolved in the air. "Keil has proved, that a young man weakened from want of nouriſhment, but in other reſpects healthy, added eighteen ounces to his weight, in the ſpace of one night, and this by the abſorption through his pores. Another perſon has been ſeen to gain 40lbs. weight, in the ſame manner, in the ſpace of a day. M. de Haen, is of opinion, that dropſical patients abſorb more than 100lbs. weight every day. It is ſuppoſed, that in general, the body abſorbs more than 1lb. every day by the pores.*" The ſkin of a middle-ſized man, is equal to about 15 ſquare feet, and if we ſuppoſe the ſkin of a dropſical perſon to be 20 ſquare feet, then will each ſquare foot imbibe 5lbs. or pints of water in one day.

In addition to theſe inſtances I will ſubjoin the following account, which was given me by a perſon of credit and judgment. A lad at Newmarket, a few years ago, having been almoſt ſtarved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 o'clock in the morning, and again at 10, and he was found to have gained near 30 ounces in weight in the courſe of an hour, though he had

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* Treatiſe of Phyſic by Zimmerman. Vol. II. p. 128.

had only drank half a glaſs of wine in the interval. The wine probably ſtimulated the action of the nervous ſyſtem, and incited nature, exhauſted by abſtinence, to open the abſorbent pores of the whole body, in order to ſuck in ſome nouriſhment from the air. Something ſimilar to this was the caſe of the negro, who, being gibbetted alive, regularly voided every morning a large quantity of urine, but diſcharged no more till about the ſame hour the next day.* The dews of the evening at Charles Town in South Carolina, imbibed by his body, ſupplying a ſuperabundance of fluids in the night, and a ſufficient quantity to ſupport perſpiration in the day. It has been obſerved that "neither hogs nor beaſts of burden ever drink in Jamaica, and yet they are continually ſweating. The air is ſo moiſt, that the abſorbing pores of theſe animals imbibe a ſufficiency of water.*" The imbibition of water through the pores of the ſkin is an acknowledged fact——" it is well known, that perſons who go into a warm bath, come out ſeveral ounces heavier than they went in; their bodies having imbibed a correſpondent quantity of water.† Part of the utility of medicated and vapour baths, depends upon this principle of imbibition by the pores; and it is ſaid that thirſt may be allayed by bathing in warm ſea water, the pores im-

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* Medical Tranſ. Vol. II. p. 105.

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* Treatiſe of Phyſ. Vol. II. p. 101.

† Goldſmith's Hiſt. of the Earth. Vol. I. p. 238.—398.

imbibing the water and carrying it to the inteſtines, but not ſuffering the diſſolved ſalt to accompany the water.

With reſpect to the quantity of water ſuſpended in the whole atmoſphere, or even in a column of the atmoſphere, of a definite baſis, incumbent on any particular ſpot, it cannot be aſertained with preciſion, unleſs we knew ſome method of depriving the air of all the water it contains, and could at the ſame time make the experiment at different diſtances from the ſurface of the earth. For it is not only probable, that a cubic yard of air, contiguous to the ſurface of the earth, contains at different times very different quantities of water, even at the ſame place, according as the ground is moiſt or dry, or the temperature of the weather warm or cold; but we have great reaſon to believe, that at the ſame inſtant of time, a cubic yard of air which touches the ſurface of the earth, contains as much water as three or four cubic yards, which are ſituated at the diſtance of thirty or forty yards above it. For the water which riſes from the ſurface of the ocean, from the perſpiration of organiſed bodies, whether vegetable or animal, or from the mere action of the ſun on a moiſt earth, in being diſſolved in the air as ſoon as it riſes, makes the air near the ſurface, heavier than that which is at a diſtance from it, and on that account the motion of the air, unleſs it be violent, will not readily mix the lower and heavier air, with the higher and lighter, and the lower air will conſequently contain more water in a definite bulk, than the higher. To what has in a former Eſſay been obſerved on this ſubject, the following illuſtration may be added. If into a deep drinking glaſs half full of water, you gently pour a glaſs of port or claret, you will ſee the wine mixing indeed itſelf ſlowly with the water, but that part of it which is near the water, will be much more impregnated, in any definite portion of time, with water, than the more remote parts; it will be a conſiderable time before the water will be uniformly diffuſed through the wine, if they are left undiſturbed; nor does a gentle undulating motion ſoon mix them, and this difficulty of mixing them would be ſtill much greater, if there was a greater difference in their reſpective weights, or if the upper parts of the wine were leſs denſe than the lower. Now this is the caſe in the air, which is not only above 800 times lighter than water, but its parts, which are far removed from the ſurface, are much leſs denſe than thoſe which are contiguous to it. That denſe air holds more water in ſolution than rarefied air, is proved from hence; that when common air is rarefied under the receiver of an air pump, a part of the water which is contained is precipitated, in the form of dew; this anſwers to the precipitation of ſalt from a ſaline ſolution, when part of the water is taken away, which held the ſalt in ſolution. Hence, as cold tends to render the air more denſe, it certainly contributes to its holding more water in ſolution than it would do, if it was more rarefied under the ſame degree of heat: but as hot air diſſolves more water than cold air, and as air is rarefied by heat, it is evident, that the denſity and heat of the atmoſphere in ſome meaſure counteract each other, with reſpect to the power the air has in diſſolving water: the law according to which this power varies, in different degrees of heat and condenſation, is not determinable from any experiments which have yet been made.

It may not be improper to take notice in this place, of an objection which is uſually made to the doctrine here advanced,——of water being ſuſpended in the air by ſolution—It is aſſerted, that water is as evaporable in an exhauſted receiver, where there is no air, as in the open air *. It is certain, that heat will evaporate water, and great degrees of it may, probably, evaporate it faſter in *vacuo*, than in the open air, inaſmuch, as the preſſure of the air may tend to obſtruct the action of the heat, in converting the water into vapour. Thus, quickſilver is not, I apprehend, evaporable in the open air, yet it has long been remarked to be evaporable in *vacuo*, as may be collected from the little globules of quickſilver, generally ſound adhering to the upper part of a barometer, and which ariſe from the vapour which inſenſibly eſcapes from the ſurface of the quickſilver in the tube. But though heat may be one cauſe of the evaporation of water, the attraction between air and water, upon whatever principle it depends, may be another. The fact moreover, upon which the objection is founded, is very queſtionable, and not generally to be admitted. A china ſaucer which contained 3 ounces of water, loſt nothing of its weight under an exhauſted receiver in the ſpace of 4 hours; whilſt a ſimilar ſaucer, containing an equal quantity of water, loſt, in the ſame time, in the open air, one drachm and eight grains; the heat of the atmoſphere being between 48 and 50 degrees *.

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* Berlin Mem. 1746. Waller de aſcen. vapo. in vacuo.

Many readers are gratified with ſeeing the general progreſs of any philo-

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* See Dr. Dobſon's ingenious Obſervations in Philoſ. Tranſ. 1777, p. 256.

philoſophical opinion, from its being firſt ſuggeſted, till its being generally admitted. The hiſtory, indeed, of philoſophy, is one of the moſt pleaſing purſuits which a ſpeculative mind can be engaged in, but it requires great leiſure and ability to cultivate it with ſucceſs. It is not every diſtant hint which he throws out, that can entitle a philoſopher to the credit of being the firſt framer of an hypotheſis; nor on the other hand are we haſtily to reject the maxim, that "all novelty is but oblivion", inaſmuch as we frequently ſee old opinions putting on the appearance of new diſcoveries, from their being dreſſed out in a new form.

Natural philoſophy principally conſiſts in exploring by experiment, the phenomena reſulting from the mutual action of different bodies upon each other. Theſe phenomena are innumerable, no arithmetic can reckon up the various ways in which terreſtrial bodies may, by natural or artificial means, be brought to operate on one another. To this cauſe may we attribute the immenſe number of volumes on experimental philoſophy, which have been publiſhed in Europe ſince *Bacon* pointed out the proper method of ſtudying nature. This circumſtance, joined to the uniformity which muſt ever attend the operations of nature in ſimilar circumſtances, may juſtly intitle different men to the honour of having made the ſame diſcoveries, it being much eaſier to make an experiment, which may have been made before, than to read all that has been written in different ages and countries on natural appearances.

Doctor Halley, in the year 1691, propoſed to the Royal Society, his opinion concerning the origin of ſprings: in this tract he expreſſes himſelf in the following manner, " the air of itſelf would imbibe a certain quantity of aqueous vapours, and retain them *like ſalts diſſolved in water*, the ſun warming the air, and raiſing a more plentiful vapour from the water in the day time, the air would ſuſtain a greater portion of vapour, as warm water would hold more diſſolved ſalts, which upon the abſence of the ſun, in the nights, would be all again diſcharged in dews, analagous to the precipitation of ſalts on the cooling of liquors."*

M. Le Roy publiſhed an ingenious diſſertation on the ſolubility of water in air, in the year 1751; among other experiments, by which he illuſtrated his hypotheſis, he obſerves that if a large, new, hollow, globular glaſs veſſel, with a narrow neck, be cloſely corked up in a clear hot day, the water contained, in the apparently dry air, will be precipitated, and form a dew in the inſide of the veſſel, whenever the veſſel is cooled, and that this dew will vaniſh, being rediſſolved by the air included in the veſſel, as ſoon as the air regains its heat.

Doctor Franklin further illuſtrated this principle, of water being ſoluble in air, in a paper which was read before the Royal Society in 1756, and afterwards printed in his works *.

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* Philoſ. Tranſ. No. 192.

In the French *Encyclopedie*, publiſhed in 1756, we meet with the following paſſage—on voit par la combien ſe trompent ceux qui s' imaginent que l'humidite qu'on voit s' attacher autour d'un verre plein d'une liqueur glacee eſt une vapeur condenſee par le froid: cet effet, de meme que celui de la formation des nuages de la pluie, et de tous les meteors aqueux, eſt une vraie precipitation chimique, par un degre de froid qui rend l' air incapable de tenir en diſſolution toute l' eau dont il s' etoit charge par l' evaporation dans un tems plus chaud; et cette precipitation eſt preciſement du me-

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* Franklin on Elec. p. 182.

me genre que celle de la creme de tartre, lorſque l' eau qui la tenoit en diſſolution s' eſt refroidie.*

Muſchenbroek, amongſt other cauſes which he aſſigns for the ſuſpenſion of vapour evidently alludes to the ſolution of water in air, and compares it to the ſolution of ſalts in water.†

But though a great many philoſophers had ſpoken of the ſolubility of water in air, before *Doctor Hamilton*, yet in juſtice to him it muſt be owned, that no one has treated the ſubject more diſtinctly, or applied it more ſucceſsfully to the explanation of various phenomena than he has done, in an eſſay which was read to the Royal Society in 1765, and afterwards publiſhed with other eſſays, by the ſame author.[*] The reader will be very well pleaſed with ſeeing this principle illuſtrated in an eſſay by Mr. White, publiſhed in 1771, in the elegant collection of Georgical Eſſays by *Doctor Hunter*[†].

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* Ency. Fran. T. 6. p. 283. Fol. Ed.

† Introd. ad Phil. Nat. Vol. II. p. 965, pub. 1769.

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[*] Philo. Eſſays by Hugh Hamilton, D. D. F. R. S.

[†] Georgical Eſſays by Doctor Hunter. Vol. II. p. 15.

ESSAY IV.

OF COLD PRODUCED DURING THE EVAPORATION OF WATER, AND THE SOLUTION OF SALTS.

ON the 27th of March 1779, when the weather had been for ſome time very dry, I put a thermometer into a glaſs of water, which had been heated to 87 degrees, by ſtanding expoſed to the direct rays of the ſun. The thermometer was then taken out, and its bulb was held oppoſite to the ſun which ſhone very bright; as the bulb grew dry by the evaporation of the water, the mercury in the thermometer ſunk very faſt; it continued for a moment ſtationary at 76 degrees, and then it roſe rapidly to 90; ſo that 11 degrees of cold had been produced during the evaporation of the water.

On another day in the ſame month, when the heat in the ſhade was 68 degrees, I put a thermometer into a glaſs of water, it ſtood at 50 degrees; upon taking it out, the mercury inſtead of ſinking from the effect of evaporation, began *immediately* to riſe from the effect of the heat of the atmoſphere upon it. I put the thermometer into the ſame water, heated to 55 degrees, and taking it out, the mercury continued *ſtationary* for ſome time, and afterwards it began to riſe. It was put into the ſame water heated to 58 degrees, and upon being taken out, the mercury did not either riſe or continue ſtationary, but it ſunk one degree; when the water was heated to 60 degrees, the thermometer upon being taken out, ſunk 3 degrees before it began to riſe. Theſe experiments were all made in the ſhade, and it ſeems as if we might conclude from them, that 57 was the degree of heat in the water, in which the cold produced by evaporation, was juſt equal to the heat produced by the atmoſphere which then ſurrounded the ball of the thermometer.

The degree of cold produced by evaporation, depends, probably, upon the quickneſs with which that is accompliſhed: now the quickneſs with which water, of a definite temperature, is evaporated, is influenced, partly by the degree of heat prevailing in the atmoſphere; partly by the wind blowing upon the thermometer; partly by the dryneſs or moiſtneſs of the air; and by other cauſes.

September 30th of the ſame year, when the heat in the ſhade was 64 degrees, and the heat of the water 60, the thermometer upon being taken out, ſtood ſtationary for three minutes, and then it roſe; there was a gentle ſouth wind. On the next day there was a cold dry wind from the north, the water and air were both at 56 degrees, and the thermometer on being taken out ſunk to 52.

Spirits of wine, ether, and many other fluids, produce cold by being evaporated, and they produce a much greater degree of cold than water, in conſequence, probably, of their being more evaporable. Thus, vitriolic ether*, which is one of the moſt volatile fluids in nature, has been obſerved to lower *Reaumur*'s thermometer 40 degrees below the freezing point (which anſwers to 90 degrees of Fahrenheit's ſcale)†. The experiment is moſt commodiouſly made, by applying a piece of fine linen wetted with ether upon the bulb of the thermometer, accelerating

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* Ether is made by diſtilling a mixture of ſpirits of wine and oil of vitriol.—Ether may be made alſo by diſtilling ſpirits of wine with the ſeveral acids of nitre, ſea ſalt, and vinegar, and it is then called he nitrous, marine, acetous ether.

† Chem. Dict. art. Ether. Or Manuel de Chymie. par. M. Baumé, p. 375.

ing the evaporation by blowing on the linen with a bellows, and moiſtening the linen as it becomes dry, or exchanging it for a freſh piece which is wetted with ether. Whoever attempts to aſcertain the degrees of cold reſpectively produced by different fluids, would do well to remark particularly the ſtate of the atmoſphere with reſpect to other circumſtances, as well as to its heat.

Sailors have a cuſtom, in a calm, to hold a wet finger up into the air, and if one ſide of it, in drying, becomes colder than another, they expect wind from that quarter. This cuſtom is not without its foundation; for an almoſt inſenſible motion of the air, will evaporate the water from one ſide of the finger ſooner than from another, and thus produce a degree of cold.

There is a ſimilar experiment, by which any one may convince himſelf that cold is produced by evaporation; let him wet a finger by putting it in his mouth, and then hold it up in the air, even in a warm room where there is no current of air, he will find that it grows cold as it becomes dry by the evaporation of the humidity.

" The method our gentlemen make uſe of to cool their liquors, is to wrap a wet cloth round the bottle and ſet it in the land wind: and, what is very remarkable, it will cool much ſooner by being expoſed thus to this burning wind, than if you take the ſame method, and ſet it in the cold ſea-breeze."*—The cold is produced by the evaporation of the water from the wet cloth, and as the *hot* land-wind will evaporate the water ſooner than the *cold* ſea-breeze, it is not to be wondered at, that the liquor is ſooner cooled when placed in the former wind than in the latter.

" *Kempfer* relates, that the winds are ſo ſcorching on the borders of the Perſian gulph, that travellers are ſuddenly ſuffocated, unleſs they cover their heads with a wet cloth; but if this be too wet, they immediately feel an intolerable cold, which would become fatal to them if the moiſture were not ſpeedily diſſipated by the heat."‡ The cold, which is produced by the act of evaporation, ceaſes as ſoon as that is finiſhed, by the cloth becoming dry.

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* Ives's Voy. p. 77.

‡ Treatiſe of Phyſic by Zimmerman, Vol. II, p. 151.

The manner of making ice in the Eaſt Indies, has an evident dependence on the principle of producing cold by evaporation here mentioned. On large open plains the ice makers dig pits about 30 feet ſquare and 2 deep; they ſtrew the bottoms of theſe pits, about eight inches or a foot thick, with ſugar canes, or with the dried ſtems of Indian corn. Upon this bed they place a number of unglazed pans, which are made of ſo porous an earth, that the water penetrates through their whole ſubſtance. Theſe pans, which are about a quarter of an inch thick, and an inch and a quarter deep, are filled, towards the duſk of the evening

ing in the winter ſeaſon, with water which has been boiled, and then left in that ſituation till the morning, when more or leſs ice is found in them, according to the temperature of the weather; there being more formed in *dry* and *warm* weather, than in that which is cloudy, though it may chance to be colder to the feel of the human body.* Every thing in this proceſs is calculated to produce cold by evaporation, the bed on which the pans are placed, ſuffers the air to have a free paſſage to their bottoms, and the pans, in conſtantly oozing out water to their external ſurface, will be cooled in conſequence of that water being evaporated by a gentle ſtream of *warm dry* air, the power of the air to evaporate water depending much upon its warmth and dryneſs.

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* Philoſ. Tranſ. for 1775, p. 252.

They have a kind of earthen jar in ſome parts of Spain, called *Buxaros* which are only half baked, and the earth of which is ſo porous, that the outſide is kept moiſt by the water filtering through; though placed in the ſun, the water in the pots remains as *cold as ice*:* and it probably is colder from the jar being placed in the ſun, becauſe the evaporation is thereby increaſed.

The *Blacks* at *Senegambia* have a ſimilar method of cooling water. " They fill tanned leather bags with it, and hang them up in the ſun; the water oozes more or leſs through the leather, ſo as to keep the outward ſurface of it wet, which, by its quick and continued evaporation, occaſions the water within the bag to grow conſiderably cool."†

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* Swinburne's Trav. p. 305.

It is common enough for labouring people, in the height of ſummer, to drink ſeveral quarts of beer or other beverage in a day; this quantity is principally diſcharged from the body by perſpiration; and the cold which is generated during the evaporation of the ſweat, greatly contributes to keep the body cool. Thus has Providence contrived to render the heat of the torrid zone leſs inſupportable to the inhabitants; an intenſe heat bathes the body in ſweat, but the ſweat being evaporated by the ſame heat which occaſioned it, a degree of cold is generated on the ſurface of the body, which would not otherwiſe have been produced.

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† Philoſ. Tranſ. 1780. p. 486.

It ſeems reaſonable to attribute the cold, which is produced in theſe and other ſimilar circumſtances, to the evaporation of the water, rather than to any other cauſe; becauſe when the bulb of a thermometer is wetted with different fluids, the cold produced has a manifeſt dependance on the evaporability of the fluid with which it is wetted. Thus, more cold is produced when the thermometer is wetted with ſpirits of wine, than when it is wetted with water, becauſe ſpirits of wine are more evaporable than water; and more is produced when it is wetted with ether, than with ſpirits of wine, becauſe ether is more evaporable than ſpirits of wine. No cold is produced when the thermometer is ſmeared with linſeed oil, or other oils of a ſimilar nature, becauſe theſe oils are not ſenſibly evaporable in the ordinary heat of the atmoſphere. Strong acid of vitriol when expoſed to the air, inſtead of loſing any thing of its weight, acquires an increaſe, by attracting the humidity of the atmoſphere; and as ſtrong acid of vitriol when mixed with water, generates a degree of heat, ſo the bulb of the thermometer, when wetted with ſtrong acid of vitriol, inſtead of being cooled, is warmed, and the mercury aſcends, in conſequence of the heat produced from the union of the acid of vitriol with the water contained in the air.

When water is reſolved into vapour, by the violence of a fall from a conſiderable height, the air will diſſolve it ſooner; and in diſſolving it ſooner, it will, probably, produce more cold than it would have done, if the ſurface of the water had not been broken: hence natural and artificial caſcades, may, probably, be ſerviceable in cooling the air ſurrounding them. This obſervation is purpoſely expreſſed in different terms, becauſe, having more than once ſprinkled the floor and ſides of a room with water in the ſummer time, when the heat of the air in the room and of the water was 68 degrees, I could not obſerve that a thermometer, hung in the middle of the room, changed its degree of heat whilſt the room grew dry. In very hot climates the effect may, probably, be different; thus we are told, that in the iſland of *St. Lewis*, in the river *Senegal*, " water poured on the floor of a room for the purpoſe of cooling the air, is dried up in an inſtant, and there is *ſome effect on the thermometer* placed in ſuch a room,"[*]

This phenomenon of producing cold by evaporation, had been mentioned by M. *Amontons* in the year 1699.[†] It had been noticed alſo by M. *Mairan* in 1749,[‡] and by *Muſſchenbroek*, in his Eſſai de Phyſique. Profeſſor *Richman*, at Peterſburgh, gave an account of ſeveral experiments, which he had made on this ſubject in 1747 and 1748,[||] but he did not explain the ſinking of the mercury in the thermometer, whilſt its bulb grew dry, on the principle of evaporation. Dr. *Cullen* has very particularly illuſtrated this principle, in a paper publiſhed in 1756; and he has there ſhewn that the cold produced was greater, when the evaporation was made in vacuo, than in the open air.* Laſtly, Profeſſor *Braun*, to whom the world is indebted for the diſcovery of freezing quickſilver, has made a further inveſtigation of this matter, by publiſhing a table of the degrees of cold produced during the evaporation of different fluids.†

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[*] Philoſ. Tranſ. 1780. p. 485.

[†] Mem. de l' Acad. des Scien. a Paris, 1699.

[‡] Diſſertation ſur le Glace.

[||] Novi Comment. Petrop. Tom. I. for 1747 and 1748.

During the ſolution of ſalts in water either cold or heat is generally produced, but more commonly cold. Fixed alkaline ſalts, Glauber's ſalt, and white vitriol, produce ſmall degrees of heat during their ſolution. Sal ammoniac produces the greateſt degree of cold, of any ſalt hitherto known.

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* Eſſays, Phyſical and Literary, Vol. II. Edinb. 1756. p. 145.

† Novi Commen. Petrop. Tom. X. 1764.

When Fahrenheit's thermometer ſtood at 68 degrees, both in the open air, and in the water which was uſed for the experiments, I ſaturated equal portions of water with ſal ammoniac, with ſaltpetre, and with ſea ſalt. The ſal ammoniac made the mercury ſink from 68 to 42 degrees, hence, 26 degrees of cold were produced; the nitre produced 17 degrees, and the ſea ſalt produced only 2 degrees of cold. I repeated the experiment with the ſea ſalt ſeveral times, and with different ſorts of it, but I could never obſerve that it produced above 2 or at moſt 2½ degrees of cold. The experiments with ſal ammoniac and ſaltpetre, agree very well with thoſe made by M. *Eller*, and mentioned in the Berlin memoires for 1750; ſince he produced almoſt 27 degrees with ſal ammoniac, and 18 with ſaltpetre. *Boerhaave*, indeed, made the thermometer deſcend through 28 degrees by diſſolving ſal ammoniac in water; but he had reduced his ſalt to a very fine powder, and dried it well before he uſed it; and a difference in the fineneſs of the powder to which the ſalts are reduced before they are diſſolved, may make a difference of a degree or two in the cold produced; for the finer the ſalt, the more ſurface has the water to act upon, and the quicker will the ſolution be performed; and as the cold is produced only by the act of ſolution, the ſooner that is accompliſhed, the leſs effect will the heat of the atmoſphere have, in reſtoring to the water, during the time of the ſolution, any part of the heat it may have been deprived of, during the immediate action of the water upon the ſalt.

Does any given kind of ſalt, during its ſolution in water, produce the ſame number of degrees of cold, whatever be the temperature of the water before ſolution? I have only endeavoured to reſolve this queſtion with reſpect to ſal ammoniac, and it ſeems to me that the quantity of cold produced, is not influenced by the temperature of the water. In the ſummer ſeaſon when the temperature of the air, water, and ſal ammoniac were each of them 70 degrees, the water ſank during the ſolution, of as much ſal ammoniac as would ſaturate it, to 44 degrees, or through 26 degrees. I thawed ſome ſnow in winter, the thermometer ſtood in the ſnow water at the freezing point, or at 32 degrees; by putting ſal ammoniac, which was equally cold, into the water, the thermometer deſcended during ſolution to ſix degrees, or through 26 degrees.

The poſſibility of freezing water in the middle of ſummer, is rightly enough inferred from this experiment. In a tub, ſuppoſe of 3 feet in diameter, place a bucket, a little taller than the tub, of 1 foot in diameter;

meter; in the bucket hang a Florence flaſk, or a flat lavender water bottle, ſo that the mouth of the bottle may be above the rim of the bucket: fill theſe veſſels with water heated, ſuppoſe, to 70 degrees. Saturate the water in the tub with ſal ammoniac, then will the 70 degrees of heat be reduced to 44, the water loſing, during the ſolution of the ſalt, 26 degrees. The water in the bucket being ſurrounded with this cold fluid, will itſelf be cooled; ſuppoſe it to be cooled only to 50 degrees, then by ſaturating it with ſal ammoniac, it will loſe 26 degrees more of its heat, and be cooled to 24 degrees. The water in the bottle being immerſed in a fluid, heated only to 24 degrees, will ſoon be cooled below the ſreezing point or 32 degrees, and conſequently will concrete into ice.

The cold, in all theſe caſes, is generated only during the time of the ſolution. The water recovers the temperature of the atmoſphere ſooner or later, according as its quantity is leſs or greater, and as the ſurface expoſed to the air is greater or leſs; it is here ſuppoſed, that the heat of the atmoſphere remains the ſame. The different degrees of cold produced by different ſalts, do not depend upon any general cauſe which has yet been diſcovered, nor is there any very ſatisfactory reaſon given for theſe, and other ſimilar productions of cold or heat. The time may come when we ſhall be able to comprehend the reaſon why the acid of nitre has ſuch different effects when mixed with ſnow from what it has when mixed with ſnow water; when mixed with ſnow water it excites a very great degree of heat; and when mixed with ſnow it produces the greateſt degree of cold that has ever yet been obſerved *. *Rerum natura ſacra ſua non ſimul tradit. Initiatos nos credimus, in veſtibulo ejus hæremus. Illa Arcana non promiſcuè nec omnibus patent; reducta et in inferiore ſacrario clauſa ſunt. Ex quibus aliud hæc ætas, aliud quæ poſt nos ſubibit, adſpiciet.*

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* Vol. I, p. 267.

ESSAY V.

OF THE DEGREES OF HEAT IN WHICH WATER BEGINS TO PART WITH ITS AIR, AND IN WHICH IT BOILS.

THE air bubbles which, in ſummer time, adhere to the inſides of decanters, water glaſſes, and other veſſels filled with water, cannot have eſcaped the obſervation of any one; I have endeavoured to aſcertain the degree of heat in which theſe bubbles begin to be formed.

Into a water glaſs filled with water I immerſed a thermometer; the heat of the water was 64 degrees; the water was ſet in a cloſet, where the ſun never ſhone, for two days; the heat remained much the ſame during that period, and there was no appearance of bubbles. The glaſs, with the immerſed thermometer, was then ſet in the ſun, and when the heat amounted to about 90 degrees, ſeveral air bubbles were found adhering to the graduated ſide of the thermometer, and ſome were beginning to be formed on the bottom and ſides of the glaſs.

Having frequently ſeen the inſides of veſſels containing water, ſtudded with bubbles, when the heat, it was apprehended, was much leſs than 90 degrees; I put a thermometer into a water glaſs at a time when it abounded with bubbles, and found that the heat of the water was not above 64 degrees.

The reſult of this experiment being very different from that of the preceding, in which the air did not begin to ſeparate itſelf from the water till the heat was about 90 degrees, I was for ſome time at a loſs how to account for the difference; recollecting, however, that the water which required 90 degrees of heat before it parted with its air, was pumped from a well fed by a ſtream, which had run four miles in the open air; and that the other water, which let go its air at 64 degrees, was pumped from a well fed by ſubterraneous ſprings, I attributed the difference in the degree of heat requiſite to make theſe waters part with their air, to the different qualities of the waters.

In order to try theſe waters under ſimilar circumſtances, two water glaſſes were filled, one with common well water, another with that which had been ſupplied by the ſtream; on being expoſed to the air, bubbles began to be formed in the well water when the heat amounted to 60 degrees, the other did not part with any of its air in the ſame degree of heat.

I was at firſt diſpoſed to think, that theſe experiments pointed out a general difference between river water and well water, with reſpect to their diſpoſition for retaining or parting with their air; but the following experiment, made at a different ſeaſon of the year, convinced me that the conjecture was not well founded.

In November, when the heat of the air had been for ſome time about 50 degrees, I took three water glaſſes, one was filled with rain water immediately after it had fallen, another with the common well water, the third with the water which came from the ſtream: the heat of theſe ſeveral waters was the ſame, namely 48 degrees; they were all gradually warmed, by ſetting the water glaſſes in hot water, and they all began to exhibit bubbles when the heat was about 60 degrees; I thought the rain waters ſhewed the moſt bubbles.

Hence it is plain, that the ſtream water does not differ from rain or well water, except accidentally, as to the degree of heat in which it parts with its air. The firſt experiment, in which the bubbles were not formed till the heat was 90 degrees, was made after there had been ſeveral days of very hot weather, and the water in being expoſed, during its courſe, to the action of the ſun, had probably loſt a conſiderable portion of its air before it arrived at the well. All river water has a vapid taſte in ſummer time, which is in part, probably, occaſioned by having loſt ſome of its air, in conſequence of its being expoſed to the rays of the ſun. Water drinkers are deſirous of having water freſh from the well; eſpecially in ſummer time, and not without reaſon, for the heat in that ſeaſon being generally above 60 degrees at our principal meal time, the water, if it has been long expoſed to the air, muſt have ſuffered a change of quality, not only from its increaſe of heat, but from a conſequent loſs of a portion of its air. The water which ſupplies the warm bath at *Matlock*, and which is drunk by invalids, is 68 degrees warm; hence it has loſt a part of the air which it would naturally contain, and, except in very hot weather, it does not exhibit any air bubbles in the decanters.

The air begins to be *viſibly* ſeparated when the heat is about 60 degrees; but it begins, probably, to be *inviſibly* ſeparated when the heat is much leſs: and the leaſt heat will be requiſite to ſeparate it, when the weight of the atmoſphere is the leaſt.

Philoſophers have invented various methods, equally concluſive, of ſhewing, that water in its ordinary ſtate, contains diſſolved in it a portion of air. And they have ſhewn, that water which has loſt a portion of this air, either by being *frozen*, or *heated*, or by long continued *agitation*, or by other means, has the property of re-abſorbing as much air from the atmoſphere as it had loſt; and they have ſhewn, that this abſorption is the ſtrongeſt at firſt, and becomes leſs and leſs powerful, as the water becomes more and more impregnated with air. Theſe and ſimilar obſervations render it probable, that water is as capable of diſſolving a certain portion of air, as it is of diſſolving a certain portion of any particular kind of ſalt. The quantity of air, which water is capable of diſſolving and retaining in ſolution, depends partly upon the temperature of the water, partly upon the weight of the atmoſphere, and partly, I conceive, upon the water's purity. From theſe circumſtances, as well as from ſome others which might be attended to in making the experiment, it has happened, that authors have given very different accounts of the quantity of air contained in water. *Boerhaave* has an experiment*, from which he infers, that there may be ſeparated from water a quantity of air equal in bulk to the water; the experiment is ingeniouſly contrived, but the concluſion, I think, is liable to ſome objections. The *Abbé Nollet* ſays, that water which has been previouſly purged of air, abſorbs, in ſix days, one thirtieth of its bulk.† *Doctor*

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* Boerh. Chem. Vol. I. p. 521.

† Hiſt. de l'Acad. 1743.

Doctor Hales obtained by diſtillation one cubic inch of air from fifty-four cubic inches of water*. Mr. *Eller* is of opinion that the portion of air contained in water does not exceed the 150th part of its bulk†. Dr. *Prieſtley* found that a pint of his pump water contained about one fourth of an ounce meaſure of air, that is, the bulk of the water was to that of the air it contained, as 64 to 1§. *M. Fontana* ſays, that the water of the *Seine* at *Paris*, after being long boiled, abſorbs in forty days one twenty eighth of its bulk of common air‡. Laſtly, *M. Cavallo* obſerves, that in a temperate degree of heat, and when the barometer is about 29½ inches, water abſorbs about one fortieth of its bulk of common air*.

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* Veg. Stat. c. 6. † Berl. Mem. 1750.

§ Philoſ. Tranſ. 1772. p. 248.

‡ Philoſ. Tranſ. 1779. p. 439.

It has been remarked in another place†, that the *atmoſpherical* air conſiſts, in part, of *fixed* air; and ſome of the moſt ſtriking differences between fixed and atmoſpherical air were there mentioned. If a bubble of atmoſpherical air of a definite bulk, ſuppoſe it equal to eleven pints, be expoſed to the action of a ſufficient quantity of water, which has been purged of its air by boiling, the *whole* of the bubble will, in a proper length of time, be abſorbed by the water; but when about ſeven pints, or even a leſs portion, have been abſorbed, the remaining part will reſemble fixed air in this—that a candle will not burn in it*. It is very probable that water which has not been boiled may have a ſimilar effect under certain circumſtances. —“ The wells at *Utrecht* are from 8 to 20 feet in depth; it has been the cuſtom to make uſe of pumps to raiſe the water, and they are then covered over with a kind of arch. When, after a certain period of time, the wells are opened, on any account, it is neceſſary to leave them uncovered for 12 hours, before any perſon deſcends into them; whoever ſhould venture to go down into them ſooner, would expoſe himſelf to immediate death. The air of theſe wells extinguiſhes candles like that acquired from fermentation or effer-

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* Cavallo on air. p. 213.

† Vol. II. p. 247.

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[*] Philoſ. Tranſ. 1772. p. 247.

effervefcence."* — Stagnating air, which has brooded, though but for a ſhort time, even over running water, is found to be ſo greatly altered in its quality, that it will extinguiſh flame, though it be ſufficiently pure to ſupport animal life. I was informed of this fact by a miner in Derbyſhire, who had frequently verified it by his own experience. In order to free a mining diſtrict from water, they frequently dig for miles together ſubterraneous aqueducts; ſupporting the ſides and roof with timber or ſtone. The mouths or outlets of theſe aqueducts or *ſoughs*, being below the level of the diſtrict to be drained, there is a conſtant ſtream of water flowing through them. Theſe *ſoughs* are many of them high enough for a man to walk upright in them, the water reaching to his middle or higher; and men with lighted candles frequently walk through them from one end to the other, in order to prevent obſtructions; it ſometimes however happens, that by the falling in of the roof, or other accidents, the ſough is in part dammed up: when this is the caſe, the water beyond the place where the obſtruction is, riſes to the roof of the ſough, and thus prevents a circulation of air, though there is ſtill a diſcharge of water through the mouth of the ſough. When an accident of this kind happens, men are ſent with candles in their hands to find out and remove the obſtruction, but before they have walked fifty yards from the mouth of the ſough, the candles go out, though they perceive no difficulty in breathing, and this extinction of the candles will take place in 24 hours, after the ſtoppage of the water has commenced.

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* Lavoiſier's Eſſays, p. 118.

Fahrenheit, *Boerhaave*, and other philoſophers, had obſerved that the degree of heat, requiſite to make water boil, was variable according to the purity of the water and the weight of the atmoſphere. Within the uſual limits of 28 and 31 inches in the barometer, *Boerhaave* was of opinion*, that there would be a variation in the heat of boiling water, amounting to 8 or 9 degrees. This ſubject has of late been examined with great accuracy by Mr. *de Luc*, and Sir *George Shuckburg*; and Mr. *Cavallo*

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* Chem. Vol. I. p. 171.

Cavallo has given us the reſult of their experiments in the annexed table, which is formed according to the ſcale of *Fahrenheit*'s thermometer*.

T A B L E.

Height of the Barometer.	Heat of boiling water according to	
	Mr. de Luc	Sir G. Shuckburg
	Parts of a Deg. deg.	Parts of a Deg. deg.
26	205,17	204,91
26½	206,07	205,82
27	206,96	206,73
27½	207,84	207,63
28	208,69	208,25
28½	209,55	209,41
29	210,38	210,28
29½	210,2	211,15
30	212	212
30½	212,79	221,85
31	213,57	213,69

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* Cavallo on air, p. 215.

The following experiment is curious in itſelf, and it illuſtrates both the nature of boiling in general, and what is here advanced relative to the heat of boiling water under different preſſures of the atmoſphere. I hit upon it many years ago, when I had another object in view. My deſign was to exhibit a ſtriking inſtance of the increaſe of dimenſions produced in fluids by various degrees of heat: in order to this, I took a large glaſs veſſel, reſembling in ſhape, ſuch mercurial thermometers as have a bulb at the bottom*, the bulb of this veſſel held above a gallon, and the ſtem had a ſmall diameter, and was above two feet in length. Into this veſſel I poured boiling water, and having filled it up to the very top of the ſtem, I corked it with a common cork as cloſe as I could. The water and the cork were at firſt contiguous to each other; but in a very little time the water began to grow cold, and as it grew cold, it contracted itſelf and ſunk very viſibly in the ſtem; and thus the firſt intention of the experiment was fully anſwered. But an unexpected phenomenon preſented itſelf,—the water, though it was removed from the fire,—was growing cold,—and had for ſome time entirely ceaſed from boiling, began to boil afreſh very violently, the bubbles were large and numerous, and continued to aſcend, into the ſpace between the ſurface of the water in the ſtem, and the cork, where they burſt, for above two hours. When a hot iron was applied to that part of the ſtem, through which the water, in contracting itſelf, had deſcended, the ebullition preſently ceaſed; it was renewed when the iron was removed; and it became more than ordinarily violent, when, by the application of a cloth dipped in cold water, that part was cooled. There is no great difficulty in accounting for theſe ſeveral appearances: by the ſinking of the water in the ſtem a *kind of vacuum* is left between its ſurface and the cork; water and other fluids boil with leſs degrees of heat, when the preſſure on their ſurface is diminiſhed; here the preſſure of the atmoſphere is wholly removed by means of the cork, and the water continues to boil, though its heat be conſtantly decreaſing. The interval between the water and the cork is not, as will be ſhewn preſently, a *perfect vacuum*; it is occupied either by the vapour of the water, or by a ſmall portion of air, or by both; heat increaſes the elaſticity of both air and vapour, and thus augments the preſſure upon the ſurface of the water; hence, the ceaſing of the ebullition on the application of the hot iron; cold diminiſhes the elaſticity of air, and condenſes vapour, and thus, the preſſure upon the ſurface being leſſened by the application of the cold cloth, the ebullition of the water became more violent. When the water ceaſed boiling I poured it on the bulb of a thermometer, and found that its heat was only 130 degrees.

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* A veſſel of this ſhape is uſually called a *Matraſs.*

Another circumſtance deſerving of notice remains to be mentioned. When the water was become cold, it had ſunk through the whole ſtem, and through part of the bulb, I then inverted the veſſel which contained it, into a tub of water, and obſerved upon the bottom of the bulb a large circular ſpot void of water. I conſidered this ſpot as a perfect vacuum, for it anſwered to the ſpace which the water, in contracting itſelf, had deſerted; and the vapour which, whilſt the water was warm, might have been ſuppoſed to occupy that ſpace, I was perſuaded, was condenſed by the cold: in order to ſee whether it was a *vacuum* or not, I pulled out the cork, whilſt it was under the ſurface of the water into which the veſſel was inverted, being certain that if it was a vacuum, it would be inſtantly filled with water. which the preſſure of the atmoſphere would make to aſcend through the ſtem. In fact, the circular ſpot was greatly diminiſhed by the aſcent of the water, but never (for the experiment was often repeated) taken wholly away? what remained muſt have contained either air, or ſome other fluid, whoſe elaſticity was a counterpoize to the preſſure of the atmoſphere, on the ſurface of the water in the tub. It would be too haſty a concluſion, from this circumſtance, to attribute the formation of the bubbles to the particles of air, from which water cannot be ſeparated by long boiling*; for it may be, that this ſmall portion of air aroſe from the ſubſtance of the cork, or from the air in the water of the tub, that water having not been boiled; or it may have been intangled in the parts of the boiling water, as it was poured into the veſſel, and not have had time to eſcape before the cork was inſerted; or, laſtly, which is the leaſt probable ſuppoſition, the vapour ariſing from the water may not be capable of being totally condenſed.

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* Licet diu ebullieriet aqua non erit aeris expers. Muſchen. de Aqua.

The phenomenon of the boiling of fluids is not very ſatisfactorily explained. It is clear, I think, from the experiment of which I have given an account, that it cannot be attributed, in all caſes, either to the eſcape of air from the interſtices of water, or to the matter of fire, as it is called, pervading the water; for the water continued boiling for two hours after it was removed far from the fire; and the air, if it contained any, was utterly inadequate to the formation of the numerous bubbles. *Boerhaave* has remarked, that bubbles of the kind here ſpoken of contain no air, but he has not aſſigned the cauſe of their origin; Dr. *Hooke* aſcribes them to the ſubtle parts of the water, which, when the preſſure of the air is removed, (probably by means of an air pump) are able to acquire the form of vapours, by that ſmall degree of heat which is left in the ambient air *: and other philoſophers † have adopted this idea, without hinting, at what Hooke ſuppoſed,

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* See Birch's Hiſt. of the Royal Society.

† The Abbe Nollet and Dr. Hamilton.

poſed, a different degree of volatility in the parts of the water.

From what has been advanced we may conclude, that the *Almighty*, when he ſeparated the chaotic maſs into air and water, did not render theſe two oceans of matter ſo wholly heterogeneous from each other, as that they ſhould be incapable of contracting any union together; they have, on the contrary, ſuch a diſpoſition to unite, as ſeems to indicate their having had a common origin; and were it not for the intervention of heat, they would, probably unite and again compoſe a common maſs. The water on the ſurface of the earth is conſtantly replete with air, and the atmoſphere is replete with water. The numerous tribe of aquatic animals, which inhabit the ocean of water, would periſh, if it contained no air; and it it is not an improbable conjecture, that the animals which exiſt in this ocean of air, would periſh if it contained no water. The air, moreover, by being abſorbed into the water, and afterwards ſeparated from it by the action of the ſun, to which it is daily expoſed, is rendered abundantly more fit for animal reſpiration than common air; and this purified air (the quantity of which, conſidering the great extent of the ſurface of the earth which is covered with water, muſt be very conſiderable) cannot but be one great means of reſtoring to the whole maſs of air, thoſe ſalubrious qualities of which it is daily deprived, by the *reſpiration* of animals, the *putrefaction* of bodies, the *combuſtion* of fuel, and other cauſes.

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* Dr. Prieſtley has obſerved, "that the ſame water, which, if examined immediately, gives only a ſmall quantity of bad air, yields *ſpontaneouſly* about ten times the quantity of pure dephlogiſticated air, after ſtanding ſome time expoſed to the *ſun*." Phil. Tranſ. 1779, p. 377. An animal will live five times as long in what is called here dephlogiſticated air, as it will in common air of the beſt quality.

ESSAY VI.

OF WATER IN A SOLID STATE; OF THE HEAT OF SPRING WATER; AND OF A PROBABLE CAUSE OF THE IMPREGNATION OF SULPHUREOUS WATERS.

THE mind of man admits with great reluctance, the truth of every teſtimony concerning matters of fact, which happen to be repugnant to the uniform experience of his ſenſes; hence the general backwardneſs to believe the miracles recorded in the bible; and hence the *Dutchman* who informed the king of *Siam*, that water in his country, would ſometimes, in cold weather, be ſo hard that men walked upon it, and that it would bear an elephant, if he were there, was eſteemed a perſon unworthy of credit, the king, as Mr. *Locke* relates the ſtory, ſaying to him, "Hitherto I have believed the ſtrange things you have told me, becauſe I look upon you as a ſober man, but now I am ſure you lie."*

Mabine, the native of *Borabora*, could ſcarcely be perſuaded, even by the information of his ſenſes, of the reality of the ſame effect. The appearance of "white ſtones," as he called hail, which melted in his hand was altogether miraculous to him; and when he had been with difficulty convinced that an extenſive field of ice was not common land, he was determined at all events to call it "white land," by way of diſtinguiſhing it from all the reſt*.

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* Locke's Eſſay on the Hum. Und. B. IV. C. XV.

This determination of the ſavage was made in the true ſpirit of philoſophy, for ice in ſmall particles is a ſpecies of earth, and in ſolid maſſes it may be conſidered as a kind of tranſparent ſtone. *The waters*, ſays Job, † ſpeaking of the effect of froſt, *are hid as* with *a ſtone*; that is, water conceals its nature, by aſſuming a ſtone-like hardneſs and conſiſtence when it becomes ice. The Ruſſians applied ice to the ſame purpoſes with ſtone, at the whimſical marriage of *Prince Gallitzen*, in 1739; an houſe, conſiſting of two apartments, was built with large blocks of ice, the furniture of the apartments, even to the nuptial bed, was made of ice; and the icy cannon and mortars, which were fired in honour of the day, performed their office more than once without burſting. *

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* Forſter's Voy. Vol. I. p. 530.

† Chap. xxxviii. 30.

Ice, however, differs from all other earths and ſtones, not only in its melting in a much leſs degree of heat than any of them, but in its being ſubject to a conſtant diminution of its weight when expoſed to the open air, in the greateſt degree of cold. It generally becomes fluid in the 33d degree of heat, as indicated by Fahrenheit's thermometer; and Mr. Boyle, by expoſing in a good balance ſomewhat leſs than two ounces of ice to a ſharply freezing air, a little before midnight, found it in the morning diminiſhed in weight ten grains.* It is probable, that this diminution of the weight of ice, is owing to the abraſion of its parts by the action of the air. The particles of air are thought to be larger than the particles of water, and may by their motion acquire force enough to ſeparate the particles of ice; or if this ſhould not be admitted, it muſt be remembered, that the air always contains a great quantity of water, the particles of which when converted into particles of ice, though in this country they are ſeldom large enough to be ſeen, always make themſelves felt by impinging upon our ſkin: theſe icy particles when put in motion may abrade the ſurface of a maſs of ice, and cauſe thereby a conſtant diminution of its weight. In confirmation of this explanation it may be obſerved, that ice ſuffers no loſs of its weight in a veſſel devoid of air, nor in a cloſe veſſel full of air.* That the icy particles, contained in a freezing atmoſphere, ſhould be able to act upon ice, cannot be a matter of difficult conception to thoſe who recollect, that the hardeſt bodies in nature ſuffer a diminution of their weight, by the friction of the minute parts of the ſame kind of bodies;

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* Manſtein's Mem. of Ruſſia.

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* Boyle's Works, Fol. Vol. III. p. 66.

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* Hamilton on the Aſcent of Vapours, p. 71.

diamond duſt being eſſentially neceſſary for the cutting or poliſhing of diamonds.

That water was diminiſhed in quantity by being frozen was known to *Hippocrates*; for he expreſsly ſays, that if a given quantity of water be frozen, and afterwards thawed, it will not fill the ſame veſſel it would have done before it was frozen *. *Pliny* was of the ſame opinion with Hippocrates, and they both of them attribute this diminution of weight to the ſeparation of the more ſubtile parts of the water during congelation†. The principal cauſe of the loſs of weight, ſuſtained by water when changed into ice, ſeems to be the inceſſant

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[*] Hippoc. de Aqua.

[†] Plin. Hiſt. Nat. Lib. II. S. 61. & Lib. XXXI. S. 3.

inceſſant action of air upon its ſurface; it is true, however, that water is, by freezing, deprived of the greateſt part of the air with which, in its fluid ſtate, it is ordinarily ſaturated; and this ſeparation of its air may contribute ſomething towards the diminution of the water's bulk; ſince water when ſaturated with air, is ſomewhat greater in bulk than when deprived of it.

It is eaſy to apprehend, that the loſs of weight which any given quantity, ſuppoſe a cubic foot, of ice will ſuffer by expoſure to the air in a given time, will depend, partly upon the hardneſs or ſoftneſs of the ice, partly upon the temperature of the atmoſphere, with reſpect to the degrees of cold and humidity, partly upon the velocity of the wind which bruſhes its ſurface, and probably enough upon the agency of other cauſes with which we are leſs acquainted. Some philoſophers have eſtimated in general terms, the loſs of weight ſuſtained by a certain weight of ice, without ſpecifying the magnitude of the ice's ſurface; others, with more accuracy, have mentioned both the weight and ſurface of the ice expoſed to the air, but then they have either omitted to ſpeak of the ice's conſiſtency: the temperature of the atmoſphere; the force and direction of the wind; or they have expreſſed themſelves in very indefinite terms concerning theſe points, ſo that we cannot be ſaid to have hitherto gained, from their experiments, any preciſe information upon the ſubject. As to the fact itſelf, the moſt common obſervation is ſufficient to aſcertain us of its truth. In long continued froſts, the ice formed in ponds and other ſmall collections of water, is ſenſibly diminiſhed every day, and often wholly evaporated; and a fall of ſnow may be ſeen conſiderably waſted in a few days, in the ſevereſt ſeaſon.

Notwithſtanding this diminution of weight, to which both ice and ſnow are ſubject in the coldeſt weather, and the thaw which they experience in the hotteſt, yet ſome have doubted whether the quantity of congealed water, be not an increaſing quantity upon the ſurface of the earth; and have even thought, that the globe of the earth muſt in proceſs of time reſemble an egg, having its diameter from pole to pole, longer than the equatorial diameter, on account of the conſtant accumulation of frozen water at the two poles.—“ After ſo many years lapſe it cannot be, I think, but that the diameter of the earth from pole to pole, from the top of the ſnow at one end of the earth, to the top of it at the other end, is much longer, than in any part under the equator, though at the creation it were (as I believe) made ſpherical.”*

In ſome mountainous countries, the proportion between the ſnow which falls at one ſeaſon of the year, and that which is diſſolved in another, approaches ſo near to an equality, that upon the ſame ſpot, the ſnow may in one year be ſeen quite through the year, in another, the laſt ſpeck of it will vaniſh in a few weeks or days, before a new ſupply is brought by the approach of winter. In colder climates, the utmoſt power of the ſummer ſun is not able to melt all the ſnow which falls in the winter. In aſcending mount *Etna*, the *Alps*, or the *Andes*, though the lower parts are found to be rich in vegetation, yet you ſoon come to a region covered, as it ſhould ſeem, with everlaſting ſnow: the height at which this region commences, does not admit much variation in the ſame latitude, but is very different in different latitudes. It begins at the diſtance of near three miles above the level of the ſea, under the equinoctial line; and at each pole, probably, it is not removed from that level ſo many hundred feet; it is found to be 600 yards nearer to the level of the *ſea* at *Teneriffe* than under the equator; and above 1200 yards nearer in *Switzerland* than at *Teneriffe**.

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* Childrey's Brit. Bacon. p. 148.

Not only the tops of high mountains in every quarter of the globe are covered at all ſeaſons of the year with ſnow, but the ocean both in the northern and ſouthern hemiſphere is, in high latitudes, replete with immenſe mountains, and extenſive plains of ice, in the greateſt heats of ſummer; and hence it has appeared probable to many, that both the ſnow upon the land, and the ice upon the ſea, receive an augmentation every year, from the continued agency of the ſame cauſe which firſt produced them.

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* Hiſto. Nat. des Glaciers Suiſſe —— the author ſays, enfin la plupart des Montagnes voſines des poles ſont convertes juſqu' á leur pied de neiges perpetuelles. This obſervation muſt not be admitted without reſtriction, if it be at all true, ſince in Greenland, and in the latitude 79 degrees, 44 minutes north, the feet of the mountains are in certain ſeaſons freed from ſnow. See Crantz Hiſt. of Greenland, Vol. I. p. 30. and Phipps's Voy. p. 52 and 70.

A philoſopher, well acquainted with the nature of the Alps, expreſſes himſelf upon this ſubject in the following manner, " one cannot doubt concerning the increaſe of all the Glaciers of the Alps: for their very exiſtence is a proof, that in preceding ages the quantity of ſnow which has fallen during the winter, has exceeded the quantity melted during the ſummer. Now not only the ſame cauſe ſtill ſubſiſts, but the cold, occaſioned by the maſs of ice already formed, ought to augment it ſtill farther, and thence both more ſnow ought to fall, and a leſs quantity of it be melted."* If this be admitted, the time will undoubtedly come when the ſea will be diminiſhed in depth, if not dried up by the converſion of the water, which is daily raiſed from it, into ſnow or ice; and had the world been as old, as ſome are fond of ſuppoſing it to be, we ſhould, probably, have had no water upon its ſurface at the preſent day. However, it muſt be owned, that no argument can be drawn againſt the antiquity of the world, from this conſideration, becauſe there is reaſon to believe that the ice and ſnow upon the ſurface of the earth, are not annually increaſing in quantity.

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* De Luc de l'Atmoſphere, Vol. II. p. 328.

tity. For, beſides the heat of the air in ſummer, there is another cauſe which tends to prevent an indefinite augmentation of congealed water — the internal heat of the earth. The general heat of the ſprings of water, ſituated deep in the bowels of the earth, is 48 degrees; in mountainous countries, I ſuſpect it to be ſomewhat leſs, but ſufficient, notwithſtanding, for the purpoſe here mentioned. When the ſnow, incumbent on any ſpot of ground, is but thin, it may ſo far cool the earth, that its internal heat may not be able to diſſolve it; but when the bed is thick enough to protect the earth from the influence of the atmoſpherical cold, that ſurface of the ſnow which is contiguous to the ſurface of the earth, may, even in the coldeſt winters, receive more heat from the earth than it does cold from the atmoſphere, and, on that ſuppoſition, I ſee no abſurdity in admitting, that it may be diſſolved at all ſeaſons of the year.

The fact I believe is certain, that ſtreams of water iſſue from the bottom of the *Glaciers* in the *Alps*, in the greateſt ſeverity of winter; ſo that whether the internal heat of the earth be admitted or not, as a cauſe ſufficient to explain the phenomenon, a conſtant thaw of the ice or ſnow, which is contiguous to the ſurface of the earth in the Alps cannot be denied; and this, added to other cauſes, may render it probable, that the quantity of congealed water has its *limit*, even in the coldeſt climates.

The ordinary heat of ſpring-water, which does not feel the viciſſitudes of the temperature of the atmoſphere, is here ſaid to be 48 degrees of Fahrenheit's thermometer; it may be worth while to add a few remarks on this ſubject.

In Auguſt 1778, when the heat of the air was 72 degrees, I tried on the ſame day, the temperature of ſeveral ſprings, reputed cold, in the neighbourhood of *Matlock*; and I found them varying in heat from 50 to 54 degrees. This variation, probably, proceeds from their ſubterraneous paſſages being ſituated at different diſtances from the ſurface of the earth, which was then much warmed by the heat of the ſummer. Or it may proceed from the ſprings being more or leſs mixed with the water which ſupplies the warm baths, the heat of that water being 68 degrees. There is a ſubterraneous paſſage upon the ſide of the hill near the *new* bath at Matlock, which terminates in a large cavern, ſituated under one of the fields in the midway between the *new* and the *old* bath; and from this cavern, which is always full, iſſues the warm water which ſupplies both the baths; and it may probably ooze out in different directions, and in different quantities, ſo as to make the neighbouring ſprings participate more or leſs of its warmth.

At *Lord Godolphin's* houſe on *Gogmagog* hills, near *Cambridge*, there is a well, above 230 feet in depth, which is dug through a ſtratum of chalk; I have frequently examined the heat of the water of this well, and conſtantly found it to be 50 degrees. At *Cherry Hinton*, a village ſituated at the bottom of theſe hills, there iſſues from the chalk a very copious ſpring, the heat of this water as it bubbles out of the earth, is, at all ſeaſons of the year, 50 degrees. I have tried the heat of ſome deep wells dug in chalk at *Bury St. Edmunds*, and found it variable from 50 to 52 degrees. —— " It has been long and generally obſerved, that as far as the limeſtone extends, that tract of ground makes the ſnow that falls on it, thaw or melt ſooner than it does on the neighbouring lands."* This is Mr. Boyle's obſervation concerning ſome limeſtone land in Ireland, and he ſays its truth was confirmed to him by a Derbyſhire miner, who aſſured him, that on contiguous diſtricts of land, ſnow was obſerved to diſſolve much ſooner on the ſoil which covered limeſtone, than on that which covered freeſtone. If theſe obſervations may be depended on, we may, perhaps, in general infer, that the heat of calcareous ſtrata is greater than that of other kinds of ſtrata, and this would furniſh a reaſon for the ſprings in chalk countries being of the warmth of 50, though the ordinary heat of ſprings be not above 48 degrees.

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* Boyle's Works, Vol. IV. p. 278.

In the middle of ſummer, when the air was 72 degrees hot, I tried the heat of ſome ſprings at *Harrowgate* in Yorkſhire. Pump water at the *Granby* Inn 48 degrees.—Old Spaw 48 degrees.—*Pewit* or *Tewit* well 48 degrees.—Sulphur well 50 degrees. The cold well at *Buxton*, examined at the ſame time of the year, was 48 degrees, and the famous Spaw at *Llanrhaid'r* in *Denbighſhire* was alſo 48 degrees; St. *Winifred's* well at Holywell in Flintſhire, was conſiderably warmer, the thermometer, when held in the ſpring as it roſe out of the earth, ſtanding at 54 degrees. I have tried a great many other ſprings in different parts of Great-Britain, and found the heat of moſt of them to be included between the limits of 48 and 54 degrees, the mean of which is 51. Springs on the ſides of high mountains, may, probably, participate of the cold which is found to be greater in elevated than in low ſituations. There is a ſpring by the ſide of the turnpike road leading over the high ground called *Otley Shevin* in York-ſhire; I obſerved the heat of this ſpring in September, when the air was warmed to 62 degrees, to be not 48, but only 45 degrees. The mean heat of ſprings near *Edinburgh* is ſaid to be 47, and at *London* 51 degrees: † this diverſity depends, probably, on the different elevations of London and Edinburgh above the level of the ſea.

I have mentioned the *Sulphur* well at *Harrowgate*, according to its uſual appellation at that place, without taking upon me to decide the long controverted queſtion, concerning the exiſtence of ſulphur in that and other waters of the ſame kind. "*Sulphur* has been long eſteemed a mineral body very common to be met with in waters; and all thoſe waters which have a ſtrong fetid ſmell, reſembling that of a foul gun, have been eſteemed to be more or leſs impregnated with ſulphur. However, Dr. *Hoffman* ſeems to doubt much of its exiſtence in the greater number of ſuch waters; and Dr. *Lucas* has affirmed, that it is not to be found in the form of ſulphur in any water whatever; not even in that of *Aix-la-Chapelle*, where a true and perfect ſulphur is found on the upper parts of the conduits through which the water paſſes; for he ſays, that, ſtrictly ſpeaking, theſe waters do not contain ſulphur ſubſtantially diſſolved in them, but are impregnated with a phlogiſton and an acid, the principles of ſulphur; which being in a volatile ſtate, are ſublimed, meet on the ſurface of the conduits, and there unite into a true and perfect ſulphur, which did not naturally exiſt in the water."† The author, from whom I have made this extract, informs us that Dr. *Rutty* maintains the exiſtence of ſulphur in mineral waters; and that both Dr. *Shaw* and Dr. *Short* found ſulphur in Harrowgate water. Notwithſtanding the teſtimony of ſuch eminent phyſicians, the more recent opinion of a phyſician, whom Dr. *Monro* conſulted on the ſubject in 1768, is againſt the exiſtence of ſulphur in ſuch waters. "I have taken particular notice of every appearance of the Harrowgate waters, and muſt own I never obſerved any appearance of ſulphur floating in them, nor any ſcum at the top of the well; neither could I meet with any perſon in that quarter, who remembered the appearance of real ſulphur ſublimed, upon taking up the ſtones at the bottom of the well, as mentioned by Dr. *Neal.*" ‡—I beg leave to add my own obſervation on the ſubject, which I made in 1780. The water in the well riſes into a circular ſtone baſon; a whitiſh cruſt adheres to the ſtone, where it is contiguous to the ſurface of the water; I ſcraped off a portion of this cruſt, and putting it on a hot iron, I found that it burned with the *flame* and *ſmell* of *ſulphur*. I do not think that this experiment abſolutely warrants us to conclude, that *actual ſulphur* is contained in this and other waters generally denominated ſulphureous; we juſtly infer from it, that ſomething is ſublimed from the water, which either of itſelf is ſulphur, or which in conjunction with the air, or ſome other principle, conſtitutes ſulphur.

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† Philoſ. Tranſ. 1775, p. 460.

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† Monro on Mineral Waters, Vol. I. p. 30. and 196.

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‡ Id. p, 196.

The proſecution of this ſubject would lead to ſpeculations too abſtruſe for my deſign; the following experiment, however, which I have frequently made, will, I hope, throw no inconſiderable light on the cauſe of the impregnation of ſulphureous waters in general.

The acid of vitriol does not act upon the common Derbyſhire lead ore, except when it is aſſiſted by heat, it then diſſolves it, and a great eſcape of air is obſerved; I made this air, as it was diſcharged from the ore, paſs through a high bended tube into a bottle full of pump water: the water, in a very little time, acquired the *fetid ſmell* of Harrowgate water,—its taſte was the ſame as that of ſuch ſulphureous waters as contain no ſalt,—it was perfectly *tranſparent*, but in the courſe of 24 hours it became *cloudy*, and loſt moſt of its ſmell,—it did not ſuffer any *precipitation* by the addition of the acid of vitriol,—*ſilver* was *blackened* both by being put into this water, and by being expoſed to the vapour which aroſe from it; from all theſe cicumſtances, it may properly enough, I think, be called an *artificial ſulphureous water*.

I have obſerved the ſame phenomena when, inſtead of lead ore, I uſed *black jack*; and I remember that once having placed a bottle, containing black jack and acid of vitriol, ſo that its neck leaned againſt a plaiſtered wall, I obſerved ſome days afterwards, that the wall was ſtained, to the diſtance of above a foot from the mouth of the bottle, of a purple colour, reſembling the purple ſediment often found in ſulphureous wells.

Air of the kind here ſpoken of, may be ſeparated from other ſubſtances, as well as from lead ore and black jack, and by other means, as well as by the acid of vitriol; and it ſeems very probable, that the waters uſually called ſulphureous, are impregnated with this kind of air, which has been ſeparated, in the bowels of the earth, from particular minerals, eſpecially ſulphureous ones. It has been remarked of Harrowgate water, that as it ſprings up it is clear and *ſparkling*, and throws up a quantity of *air bubbles*.

During the proceſs of impregnating water with air, by diſſolving lead ore in the acid of vitriol, a part of the glaſs tube was coated with a thin pellicle of ſulphur, which had accompanied the air in its aſcent: May not the ſulphur ſublimed from Harrowgate water, have accompanied the air which gives it its ſmell? Is it certain that *this kind of air* does not conſiſt of attenuated parts of ſulphur, which have acquired an elaſtic force, and which cannot be condenſed in water? Or is it not more probable, that this kind of air is one of the conſtituent parts of ſulphur, than ſulphur itſelf? Does this air, and the inflammable air ſeparable from ſome metallic ſubſtances, by ſolution in acids, conſiſt of *oleaginous* particles in an elaſtic ſtate?

If the reader wiſhes to impregnate common water with the ſulphureous properties of Harrowgate water, he may do it in the following ſimple manner.—Into an apothecary's vial, holding four or five ounces, put ſome pounded lead ore, and pour upon it ſome acid of vitriol; (there is no occaſion to be ſolicitous about the proportions of the lead ore and acid, for if there be more or leſs ore than the acid can diſſolve, ſtill air enough for the purpoſe will be diſcharged;) wrap a few folds of wet linen round one end of a bended tube, inſert this end into the neck of the vial ſo cloſely, that no air may paſs out of the vial except through the tube; the end of the tube ſhould be at ſome diſtance from the ſurface of the acid. Put the other end of the tube into a bottle full of water, then, by ſetting the vial on the hot bar of a grate, or by ſome other means, heat the acid, and as ſoon as it is heated, it will begin to act on the lead ore, and a great quantity of air will be diſcharged, which will paſs through the tube into the water in the bottle, and in a few minutes the water will be ſtrongly impregnated with the ſulphureous properties of Harrowgate water. Beſides its ſulphureous impregnation, Harrowgate water contains ſea ſalt; and moſt other ſulphureous waters contain ſome ſalt or other, ſo that, to make a complete imitation of them, the ſalts which they ſeverally hold ſhould be added in due proportion, to the water impregnated with the air here ſpoken of.

Though I am greatly diſpoſed to believe, that ſulphureous waters are impregnated with their peculiar ſmell and taſte, after the manner I have deſcribed; yet, to aſſiſt the reader's conjectures concerning the origin of this impregnation, I will mention another way in which it may be ſuppoſed to ariſe, and which will account for the ſaline taſte as well as the ſmell of the water.

I know not whether any ſpecies of maritime plants, containing ſea ſalt, will impregnate water with a ſulphureous ſmell by means of *putre-*

faction; nor whether all of them will do it by means of *combuſtion*, but that one of them will do it I can have no doubt: I allude to the *bladder fucus* or *ſea wrack*, which is burned on our coaſts for the making of *Kelp*. It has been mentioned before,[*] that ſea wrack when burned to a black coal, will yield, by being boiled in water, a great quantity of common ſalt; and I would now remark, that the water extracts from the black aſhes, not only a great quantity of common ſalt, but *ſomething* elſe alſo, by which, without loſing its tranſparency, it acquires both the ſmell and ſulphureous taſte of Harrowgate water; and by which it is enabled, like that water, to blacken ſilver and white paint.

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[*] Vol. I. p. 137.

This *ſomething* I am ſenſible may be what chemiſts call *liver of ſulphur*, or an union of ſulphur with fixed alkali, and it would not be difficult to explain its formation during the combuſtion of the ſea wrack; no ſulphur however can be precipitated from the water by the acid of vitriol, though that acid turns it, as is the caſe with Harrowgate water, a little cloudy. The air extracted from iron by the acid of ſea ſalt, impregnates water with a ſmell ſomewhat reſembling that of Harrowgate water, but its difference both from the natural and the artificial ſulphureous waters, may be eaſily diſtinguiſhed, eſpecially after the water has ſtood a few hours expoſed to the air.

ESSAY VII*.

OF DERBYSHIRE LEAD ORE.

LEAD ore, as dug out of the mine, is generally much mixed with ſpar, limeſtone, and other ſubſtances, bulk for bulk, lighter than the ore itſelf. It undergoes various dreſſings before it becomes a merchantable commodity, the general tendency of which is to free it, as much as poſſible, from every heterogeneous impurity.

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* The ſubſtance of this Eſſay was printed in the Philoſ. Tranſ. 1768.

Suppoſe that a cubic foot of lead ore, which contained no ſpar or other extraneous matter, would weigh 7800 ounces, and that a cubic foot of ſpar, which contained no lead ore or other foreign ſubſtance, would weigh 2700 ounces, then would a mixture, conſiſting of a cubic foot of pure lead ore, and a cubic foot of pure ſpar, weigh 10500 ounces, and one cubic foot of ſuch a mixture would weigh 5250 ounces. It is obvious that according to the different proportions in which the particular kinds of ſpar and lead ore here aſſumed, are ſuppoſed to be mixed together, a cubic foot of the mixture will have different weights, the limits of which are on the one hand 7800, and on the other 2700 ounces; it never can weigh ſo little as 2700 ounces, for then it would conſiſt intirely of ſpar without any lead ore; nor can it ever weigh ſo much as 7800 ounces, for then it would conſiſt intirely of lead ore without any ſpar.

From this view of the matter it is evident, that the purchaſing of lead ore by the meaſure, which is the general, though not the univerſal cuſtom in *Derbyſhire*, is a mode liable to ſome exception; ſince a diſh, containing any definite meaſure, muſt have different weights, according as the ore with which it is filled is more or leſs free from ſpar. And it is ſcarce poſſible, by repeated dreſſings, to ſeparate all the ſpar from an ore, or equal portions of it from equal portions of ore.

There is a diverſity, however, in the weights of equal meaſures of lead ore, which, probably, does not ariſe from ſparry or other heterogeneous accretions, but from the nature of the ore itſelf. I have carefully calculated the weight of a cubic foot of many of the Derbyſhire lead ores; the weight of a cubic foot of the lighteſt which I met with was 7051 ounces, and the weight of a cubic foot of the heavieſt was 7786 ounces; the difference amounting to between a ninth and a tenth part of the weight of the lighteſt. There are, probably, other ores of lead, the weights of equal bulks of which differ more than theſe here mentioned; but the difference between theſe is ſufficient to ſhew the great uncertainty of purchaſing lead ore by the meaſure, ſince ten diſhes of one ſort of ore may not weigh more than nine diſhes of another ſort, though both the ſorts are equally well dreſſed.

Lead ore is not always of the ſame goodneſs in the ſame mine, nor even in the ſame part of the ſame mine; and, what is more remarkable, the different parts of the ſame lump of ore have in equal bulks different weights. I could not eaſily have believed this, unleſs a variety of experiments had convinced me of the fact.

They were employed lately at *Holywell* in ſmelting a lead ore from the *Iſle of Man*; the ore was rich in ſilver. A lump of this ore, weighing about ten ounces, was broken into ſeveral pieces, and ſuch of the pieces were ſelected as appeared to the eye to be wholly pure. I eſtimated the weight of a cubic foot of ſix of theſe pieces,

and

and found that a cubic foot of the lighteſt kind would have weighed 6565 ounces, and a cubic foot of the heavieſt kind would have weighed 7636 ounces. Suppoſing the weight of a cubic foot of water to be denoted by 1000, the mean weight of a cubic foot of the ſix different pieces of this ore, may be expreſſed by 7115 avoirdupoiſe ounces.

A very pure ſpecimen of teſſellated lead ore, from a mine near *Aſhover* in *Derbyſhire*, was broken into ſix pieces, weighing near one ounce each. A cubic foot of the lighteſt of theſe pieces would have weighed 7326 ounces, and a cubic foot of the heavieſt would have weighed 7786 ounces. The mean weight of a cubic foot of the ſix pieces was 7566.

At the ſame mine they frequently meet with ſmall quantities of ſteel-grained lead ore. Six different pieces of the ſame lump of this kind of ore were choſen, each of which appeared quite free from ſpar and every other impurity. A cubic foot of the lighteſt of theſe pieces would have weighed 7188 ounces, and a cubic foot of the heavieſt would have weighed 7442 ounces. The mean weight of a cubic foot of the ſix pieces was 7342.

Other lumps of ore, from different mines, were reſpectively broken into different pieces, and ſcarcely any two equal pieces of the ſame lump were obſerved to agree in weight. This diverſity in the weights of equal bulks of the ſeveral pieces of the ſame lump of ore may be owing, either to the different proportions in which the conſtituent parts of the ore are combined in the ſeveral pieces; or to the different quantities of extraneous ſubſtances imperceptibly mixed with them, or, which ſeems moſt probable, to a diverſity in the ſize or configuration of their pores.

But be the cauſe of this diverſity what it may, the fact, I believe, is certain, and by no means ſingular; for not to mention the varieties obſervable in the weights of equal bulks of different pieces of roll brimſtone, of corroſive ſublimate, of caſt ſteel, and other factitious ſubſtances, the natural ſpars generally found along with lead ore are ſubject to a ſimilar diverſity, though not, perhaps, in an equal degree.

A piece of *rhomboidal*, otherways

called *refracting* or *lantern ſpar*, was broken into four ſmaller pieces, the weights of a cubic foot of each of which were 2675, 2687, 2715, 2723; the medium of the four is 2700 ounces. Mr. *Cotes* fixes the weight of a cubic foot of Iceland cryſtal at 2720, and *Wallerius* fixes it at 2700 ounces.

The weights of a cubic foot of four pieces of the ſame lump of *cubical ſpar* were 3204, 3218, 3222, 3231; the medium of the four is 3219 ounces.—Moſt of the ſpars met with in *Derbyſhire* are either *rhomboidal* or *cubical*; they are eaſily diſtinguiſhed from each other by a view of their ſhape, when their angles can be diſcerned; and when the ſhape cannot be eaſily ſeen, the nature of the ſpar may be aſcertained by touching it with an acid; the rhomboidal ſpar always efferveſcing with an acid, and the cubical reſiſting its action. The lead ſmelters make great uſe of the cubical ſpar as a *flux* for ſuch lead ores as do not readily melt: it is curious to ſee its effect; a few ſhovels full of it, thrown upon a heap of red hot ore, immediately melting down the ore into a liquid, though the longeſt continuation of the ſame degree of heat, without the addition of the ſpar, would not have been ſufficient for the purpoſe.

Six ounces of fine teſſellated lead ore were put into a crucible and expoſed, at firſt, to a gentle, and afterwards to a ſtrong fire: the ore grew red, and emitted fumes which ſmelled of ſulphur; at length it melted, and the fumes became very copious; they were accompanied with a yellowiſh flame upon the ſurface of the melted ore, and when collected had a whitiſh appearance. The crucible, after the ore had continued a full hour in perfect fuſion was taken from the fire, and when it was cold it was broken. The maſs which it contained weighed five ounces and an half; there was no ſcoria obſervable on its ſurface, nor were any particles of metal formed, it was ſtill an ore of lead.

The maſs remaining from the laſt experiment was put into a freſh crucible, and expoſed to a ſtrong melting heat; the fumes which aroſe from it ſeemed to be heavy; they brooded over the ſurface of the melted maſs in undulating flames, which now and then appeared like burning zinc.* The lead was now formed, and many particles of it were ſublimed to at leaſt ſix inches above the ſurface of the liquid in the crucible. After letting the crucible continue two hours in this ſtate, I poured out its contents, and found them conſiſting partly of lead, partly of lead ore, and partly of a very minute portion of browniſh ſcoria. I repeated this experiment with the ſame ſucceſs.

Theſe experiments prove, that ſome ſubſtance or other is contained in lead ore, which muſt be diſperſed before the ore can be formed into lead; and they ſhew too, that it requires a conſiderable time to effect the diſperſion of this ſubſtance, ſince ſix ounces of ore, though kept three hours or more in complete fuſion, were not wholly brought into the form of lead; they inſtruct us alſo to believe that the lead in this kind of ore is in its metallic ſtate, as the ore was changed into lead without the addition of any ſubſtance containing the inflammable principle; and, laſtly, they render it probable, that the fumes, ariſing from melted ore, carry off with them no inconſiderable portion of the lead itſelf. At the great ſmelting houſes in Derbyſhire, they put a ton of ore at a time into the furnace, and work it off in eight hours; the ore might be wholly melted in one hour, but the lead, perhaps, is not formed in the greateſt

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* It may deſerve to be inquired whether zinc may not be contained in lead, iron and other ores, more frequently than is ſuppoſed.

eſt poſſible quantity in eight hours.

Some fine teſſellated lead ore from Derbyſhire was pounded into ſmall lumps, each about the ſize of a pea, and carefully picked from ſpar and other impurities. Sixteen ounces of this ore, thus previouſly cleanſed, were diſtilled in an earthen retort; as ſoon as the ore felt the fire, the ſtopple of the quilled receiver had a ſtrong ſmell, reſembling that of the inflammable air, ſeparable from ſome metals by ſolution in acids; ſoon after a ſmall portion of a liquid came over into the receiver; the fire was then raiſed till the retort was of a white heat, when a black matter began to be ſublimed into the neck of the retort; the operation was then diſcontinued. This experiment was undertaken with a view of ſeeing whether ſulphur could be ſeparated from lead ore, as it may be from ſome ſpecies of the pyrites, by diſtillation, and it appears from the iſſue of the experiment that it cannot, at leaſt in the degree of heat which is requiſite for ſubliming the ore. Upon breaking the retort I found, that the ore had been melted during the operation, for there was a conſiſtent cake of ore of the figure of the bottom of the retort; the weight of this cake was fifteen ounces and an half, the weight of the liquid in the receiver, and of the black matter which had been ſublimed, did not together amount to one quarter of an ounce, ſo that a quarter of an ounce or more had been diſperſed, probably, in the form of air, or ſome elaſtic fluid. The ore by this proceſs had loſt one thirty-ſecond part of its weight. The liquid did not efferveſce with either acids or alkalies; nor did it produce any change in the colour of blue paper, yet I am certain, from experiment, that one drop of oil of vitriol, though diluted with two ounces of water, would have produced a ſenſible redneſs on the blue paper which I uſed. The liquid, notwithſtanding, had an acid taſte, and a pungent ſmell, reſembling that of the volatile vitriolic acid. The black matter which had been ſublimed into the neck of the retort, was examined with a microſcope, and it appeared to be pure lead ore. The melted ore which was found at the bottom of the retort, had not any appearance of ſcoria, or of lead, upon its ſurface.

Some phenomena attending this experiment deſerved, I thought, a further inveſtigation. I therefore diſtilled another 16 ounces of ore, but with a fire ſtronger and continued for a longer time, than in the preceding experiment: the quantity of liquid was much the ſame, there was a ſmell of ſulphur, and, perhaps, to the amount of half a grain of ſulphur was found in the receiver; the ore was in this experiment ſublimed into the neck of the retort, to the thickneſs of one fourth of an inch. There was found, as before, a cake of melted ore at the bottom of the retort, but no ſenſible portion of either *lead* or *ſcoria*; * ſo that we may ſafely conclude, that lead ore cannot be decompoſed by the ſtrongeſt fires in cloſe veſſels, but that it may be ſublimed in them. The ore had loſt near an ounce of its weight.

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* I have ſaid no ſenſible portion; there was, however, an appearance of ſcoria adhering to the ſide, and an appearance of lead adhering

Though the experiment is ſufficiently troubleſome, I was not deterred from making it once more; for I wanted to ſee whether lead ore could be wholly ſublimed; as I thought that philoſophers might thereby form ſome conjectures of the efficacy of ſubterraneous fires in ſubliming

adhering to the bottom of the retort; but the quantity of each was exceedingly ſmall, and they were both, probably, produced from that minute decompoſition of the ore which produced the ſulphur, and which would not, I think, have taken place in any degree, had there been no communication with the external air; but the orifice of the quilled receiver was not always cloſely ſtopped during the diſtillation.

in lead ores, and, perhaps, ores of other metallic ſubſtances. The event of this third experiment was perfectly correſpondent to that of the two former, with reſpect to the production of liquid, and the ſeparation of air, which was caught in a bladder, but was not found to be inflammable: the lead ore too was ſo plentifully ſublimed into the neck of the retort, that it quite plugged it up for above three inches in length. Upon diſcontinuing the fire, which had been raiſed to a degree of heat exceedingly great, I found the retort was cracked, and that the cake at its bottom was very different from what was found at the bottom of the other retorts, which had ſtood the fire without cracking; for this cake was covered with a black glaſſy ſcoria $\frac{1}{4}$ of an inch in thickneſs, and the ore which laid under it, was in part changed into *lead*, and the whole of the ore did not weigh quite ten ounces, ſo that above 6 ounces had been loſt by eſcaping through the crack. By a communication with the air through the crack, the ore was decompoſed, and thus both *lead* and *ſcoria* were formed, which in the other experiments, for want of ſuch a decompoſition, could not be formed. There was a thin coat of ſulphur alſo which lined the inſide of the receiver, and this ſulphur, probably, aroſe from the decompoſition of the ore, ſince none, or next to none, was obſerved in the other diſtillations of the ore. I found that the weight of a cubic foot of the ore, which had been ſublimed into the neck of the retort, was 7500 ounces; which ſufficiently agrees with the weight I had before aſcertained of this kind of ore. A cubic foot of the black glaſſy ſcoria weighed 3333 ounces; and the metallic cake which laid under it, and which conſiſted partly of lead, and principally of ore not quite changed into lead, gave 8738 ounces to the cubic foot.

Finding that ſulphur could not be ſeparated from lead ore by diſtilling it in cloſe veſſels without addition, and yet being much diſpoſed to think, that it contained a conſiderable portion of ſulphur, I firſt thought of diſtilling it with charcoal duſt, iron filings, ſand, and other additions; but recollecting that ſulphur might be ſeparated from antimony by ſolution in acids, I thought it not improbable, that it might be ſeparated from lead ore by the ſame means, and the ſucceſs of the following experiment abundantly juſtified the conjecture.

Upon ten ounces of lead ore, cleanſed as in the preceding experiments, I poured five ounces of the ſtrongeſt fuming ſpirits of nitre; this ſtrong acid not ſeeming to act upon the ore, I diluted it with five ounces of water; a violent ebullition, accompanied with red fumes, immediately took place; the ſolution of the ore in this *menſtruum* became manifeſt, and when it was finiſhed, there remained floating upon the ſurface of the *menſtruum* a cake of fine yellow ſulphur, perfectly reſembling common ſulphur.

I repeated this experiment a great many times, in order to aſcertain the quantity of ſulphur contained in lead ore, and ſeparable therefrom by ſolution in acid of nitre. The reſults of different experiments were ſeldom the ſame; the matter ſeparable from the ore by ſolution, after being repeatedly waſhed in large quantities of hot water, in order to free it from every ſaline admixture, ſometimes amounted to more, ſometimes to leſs than one-third of the weight of the ore. This matter may, for the ſake of diſtinction, be called crude ſulphur. Its apparent purity might induce a belief that it contained no heterogeneous mixture, yet the following experiments ſhew how much we ſhould be deceived in forming ſuch a conjecture, and how rightly it is denominated crude ſulphur.

From one hundred and twenty parts, by weight, of lead ore, I obtained, by ſolution in acid of nitre, ſubſequent waſhing in hot water, and drying by a gentle fire, forty parts of a ſubſtance which looked like ſulphur: theſe forty parts were put on a red-hot iron, the ſulphur was made manifeſt by a blue flame and pungent ſmell. When the flame went out, there remained upon the iron unconſumed twenty-ſix parts of a greyiſh *calx*; the weight of the ſulphur which was conſumed muſt therefore have amounted to fourteen parts, or between one eighth and one ninth part of the weight of the ore. It has been obſerved, that the weight of the matter, ſeparable from lead ore by ſolution in acid of nitre, ſometimes exceeded, and ſometimes fell ſhort of, one third part of the weight of the ore; this variety, as far as I have been able to obſerve, does not extend to the quantity of ſulphur contained in a given quantity of ore, it depends upon the quantity of *calx* remaining after the burning of the ſulphur. Different lead ores will doubtleſs contain different quantities of ſulphur; but that the ſulphur contained in the lead ore which I examined, conſtitutes between one eighth and one ninth part of the weight of the ore, is a concluſion upon which, from a variety of experiments, I am diſpoſed to rely.

There are ſaid to be annually ſmelted in *Derbyſhire* about ten thouſand tons of lead ore ;* now if means could be invented (which I think very poſſible) of ſaving the ſulphur contained in ten thouſand tons of ore, ſuppoſing that the ore ſhould only yield one tenth of its weight of ſulphur, though it unqueſtionably contains more, *Derbyſhire* alone would furniſh annually one thouſand tons of ſulphur, the value of which would annually be about fifteen thouſand pounds. I mention this circumſtance thus publicly, in hopes that the lead ſmelters may be induced to proſecute the ſubject. If the ſulphur contained in the lead ore could be collected, it would not only be a lucrative buſineſs to the ſmelters, but a great ſaving to the nation. We at preſent import the ſulphur we uſe, and the conſumption of this commodity is exceeding great, in the making of gunpowder, in forming the mixture for covering the bottom and ſides of ſhips, * and in a great variety of arts. The ſmelters need not be apprehenſive leſt the quality of the ore ſhould be injured by extracting the ſulphur. Eighteen hundred weight of ore, from which the ſulphur has been extracted, will certainly yield as much lead as twenty hundred weight of ore, from which the ſulphur has not been extracted, and it will, probably, yield more. Arſenic is extracted

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* This eſtimate is I have reaſon to think too high.

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* This mixture is made of one part of tallow, of one part of brimſtone, and of three parts nearly of roſin. The tallow and roſin are melted together, and the brimſtone is ſtirred into them; 140 pounds of brimſtone is enough for a veſſel of 140 tons.

tracted from a particular ore in Saxony, by roaſting the ore in a furnace, which has a long horizontal chimney; the chimney is large, has many windings and angles, that the arſenical vapour which ariſes from the ore may be the more eaſily condenſed: the arſenic attaches itſelf like ſoot to the chimney, and is from time to time ſwept out. It is very probable, that by ſome ſuch contrivance the ſulphur contained in lead ore might be collected. The ſmelters call every thing ſulphur which is volatilized during the roaſting or fluxing of an ore; but none of thoſe with whom I have converſed, had any notion that common ſulphur could be ſeparated from lead ore.

The greyiſh calx which remained

upon the iron after the ſulphur was conſumed, was put upon a piece of lighted charcoal; the heat of the charcoal being quickened by blowing upon it, a great number of globules of lead were formed upon its ſurface. From hence it appears, that this calx is not an unmetallic earth contained in the ore, which the acid of nitre could not diſſolve; but a calx of lead, probably produced by the violent action of the acid, and which, by the addition of phlogiſton, may be exhibited in its metallic form. The quantity of this calx depends much upon the action of the acid upon the ore; if that action is violent, the calx is in greater abundance than if it be moderate; and I am not certain whether the experiment might not be ſo managed, that there would be little or no calx remaining; that is, a given quantity of ore might be ſo diſſolved in the acid of nitre, that nothing would remain undiſſolved except the ſulphur. But I have not yet perfectly ſatisfied myſelf as to the conſtituent parts of lead ore. I am certain that it contains *lead*, and *ſulphur*, a *liquid*, and *air*: of the exiſtence of the three firſt there can be no doubt, from what has been ſaid, and the air is rendered beautifully apparent by the following experiment.

Let ſome lead ore be reduced into a fine powder, put it into a narrow-bottomed ale glaſs, fill the glaſs three parts with water, drop into the water a portion of the ſtrong acid of nitre, you may judge of the requiſite quantity by ſeeing the ſolution commence, and you will obſerve the ore univerſally covered with bubbles of air, theſe will buoy the ore up in large tufts to the ſurface, and the air will continue to be ſeparated from the ore till the acid becomes ſaturated with the lead. The ſalt ariſing from the union of the nitrous acid to the lead often appears cryſtallized upon the ſurface of the menſtruum in this experiment; and if, when the menſtruum is in that ſtate, a little freſh acid be added, the ſalt inſtantly cryſtallizes and falls down to the bottom of the glaſs, the acid having abſorbed the water which held it in ſolution. When lead is diſſolved in the manner here mentioned, by a very diluted acid of nitre, there is no appearance of ſulphur upon the ſurface of the menſtruum, there is found at its bottom a black matter, which is the ſulphur.

But though lead, and ſulphur, a liquid, and air*, are unqueſtionably conſtituent parts of lead ore, I do not take upon me to ſay, that they are the only conſtituent parts: it is well known, that, during the ſmelting of lead ore, a third part or more of its weight is ſome how or other loſt, ſince from one and twenty hundred weight of ore, they ſeldom obtain above fourteen hundred weight of lead. What is loſt partly conſiſts of a ſcoria which floats upon the ſurface of the lead during the operation of ſmelting, and partly of what is ſublimed up the chimney and diſſipated in the air. The ſcoria, I apprehend, would be very little, even from a ton of ore, if the ore was quite free from ſpar: it is the ſpar which is mixed with the ore that conſtitutes the main portion of the ſcoria*. I have in my poſſeſſion a ſolid maſs of ſcoria, which accidentally flowed out from a ſmelting furnace, and which in colour and conſiſtency perfectly reſembles grey lime-ſtone, it receives a poliſh as fine as marble, and it might perhaps with advantage be caſt into moulds for paving ſtones, chimney pieces, and other matters. It ariſes from the ſpar mixed with the ore, and, by the addition of cubical ſpar to the ore during its fuſion, its quantity might be increaſed at no great expence, in any proportion. That part of the ore which is ſublimed and diſperſed in the air, conſiſts partly of the ſulphur which is decompoſed, and partly of lead; this ſublimed lead attaches itſelf in part to the ſides of the chimney of the ſmelting furnace; the reſt of it flies up into the air, from whence it falls upon the ground, poiſoning the water and herbage upon which it ſettles. This ſublimed lead might be collected either by making it meet with water, or with the vapour of water, during its aſcent, or by making it paſs through an horizontal chimney of a ſufficient length.

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* I have ſeparated inflammable air from lead ore, by diſſolving it in the acid of ſea ſalt.

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* The ſpar without queſtion augments the quantity of the ſcoria, yet the lead ore, which appears to the eye to be quite free from ſpar, yields a conſiderable portion of a black glaſſy ſcoria, when urged with a ſufficient fire.

It is not eaſy to determine with preciſion the quantity of this ſublimed lead; a general gueſs, however, may throw ſome light upon the ſubject. They uſually at a ſmelting houſe work off three tons, or ſixty hundred weight, of lead ore every twenty-four hours; the ſulphur contained in ſixty hundred weight of ore, we will ſuppoſe to be ſeven hundred weight, and the lead to be forty hundred weight; the air, liquid, ſcoria, and ſublimed lead muſt together, upon this ſuppoſition, amount to thirteen hundred weight; now, admitting three hundred weight of the thirteen to be ſublimed lead, it is evident that, could it be collected, there would be an annual ſaving at each ſmelting houſe of above fifty tons, which, ſuppoſing it to be worth four pounds *per* ton, would amount to above two hundred pounds a year. The price, if not the quantity of lead ſublimate, here aſſumed, is, probably, below the truth; but my end is anſwered in giving this hint to perſons engaged in the ſmelting buſineſs.

The following experiments, though upon a different ſubject, may not be unacceptable to the lovers of chemiſtry, as I do not remember to have any where met with them.

It is commonly known, that the ſurface of melted lead becomes covered with a pellicle of various colours. I undertook ſome experiments in the courſe of laſt winter, with a view to aſcertain the order in which the colours ſucceeded each other. The lead which lines the boxes in which tea is imported from China happening to be at hand, ſome of it was melted in an iron ladle; but I was much ſurprized to find that its ſurface, though it was preſently covered with a duſky pellicle, did not exhibit any colours. Imagining that the heat was not ſufficiently ſtrong to render the colours viſible, the fire was urged till the ladle became red hot, the calcined pellicle upon the ſurface of the lead was red hot alſo, but it was ſtill without colour. The ſame parcel of lead was boiled in a crucible for a conſiderable time; during the boiling a copious ſteam was diſcharged, and the ſurface of the lead, as is uſual, became covered with a half vitrified ſcoria. The lead which remained unvitrified was then examined, and it had acquired the property of forming a ſucceſſion of coloured pellicles, during the whole time of continuing in a ſtate of fuſion.

Another portion of the ſame kind of lead was expoſed to a ſtrong calcining heat for a long time; the part which remained uncalcined did, at length, acquire the property of exhibiting colours ſufficiently vivid.

Theſe experiments induced me to conclude, that the Chineſe lead was mixed with ſome ſubſtance from which it was neceſſary to free it either by ſublimation or calcination, before it would exhibit its colours. It would be uſeleſs to mention all the experiments which I made before I diſcovered the heterogeneous ſubſtance with which I ſuppoſed the Chineſe lead was mixed. At laſt I hit upon one which ſeems fully ſufficient to explain the phenomenon. Into a ladle full of melted Derbyſhire lead, which manifeſted a ſucceſſion of the moſt vivid colours, I put a ſmall portion of tin, and obſerved, that as ſoon as the tin was melted, and mixed with the lead, no more colours were to be ſeen. I do not know preciſely the ſmalleſt poſſible quantity of tin, which will be ſufficient to deprive a given quantity of lead of its property of forming coloured pellicles, but I have reaſon to believe that it does not exceed one five thouſandth part of the weight of the lead.

Derbyſhire lead, which has loſt its property of exhibiting colours by being mixed with tin, acquires it again, as is mentioned of the Chineſe lead, by being expoſed to a calcining heat for a ſufficient time; the tin, it is ſuppoſed, being ſeparated from the lead by calcination, before all the lead is reduced to a calx.

Some calcined Chineſe lead was *reduced* to its metallic form by burning ſome tallow over it. The *reduced lead* gave, when melted, coloured pellicles; the calx of tin, which we ſuppoſe to have been mixed with the calcined lead, not being ſo eaſily reducible as that of lead.

I find that *zinc* is another metallic ſubſtance which has the ſame property as tin with reſpect to the depriving lead of its power of forming coloured pellicles; but it does not, I think, poſſeſs this power in ſo eminent a degree as tin. I put ſmall portions of *biſmuth* alſo into melted lead, but the lead ſtill retained its quality of forming colours. I melted together ſome ſilver and lead, but the lead did not thereby loſe its power of forming colours. A little tin added to a mixture of lead and biſmuth, or to a mixure of ſilver and lead, immediately takes away from the reſpective mixtures the faculty of forming coloured pellicles.

This quality of tin has hitherto, as far as I know, been unobſerved; but every new fact, relative to the actions of bodies one upon another, ought to be recorded. The change, produced in lead by the admixture of a ſmall portion of tin is much felt by the plumbers, as it makes the metal ſo hard and harſh, that it is not without difficulty they can caſt it into ſheet lead. If their old lead does not work ſo willingly, nor exhibit colours ſo readily, as new lead, they may refer the difference to the ſmall quantity of tin contained in the ſolder, from which old lead can ſeldom be thoroughly freed.

With reſpect to the order in which the colours ſucceed one another upon the ſurface of melted lead, it ſeems to be the following one; *yellow*, *purple*, *blue*, —*yellow*, *purple*, *green*, —*pink*, *green*, —*pink*, *green*. Upon exhibiting the bright ſurface of melted lead to the air, I have often obſerved theſe ten changes to follow one another in a more or leſs rapid ſucceſſion, according to the degree of heat prevailing in the lead. If the heat is but ſmall, the ſucceſſion ſtops before it has gone through all the changes; but with the greateſt heat I did not obſerve any further variation. All the colours are very vivid, and each ſeems to go through all the ſhades belonging to it before it is changed into the next in order.

The formation of theſe colours may be explained from what has been advanced by Sir *Iſaac Newton*, and illuſtrated by the very ingenious experiments of Mr. *Delaval*, relative to the ſize of the particles conſtituting coloured bodies.

ESSAY VIII.

OF THE SMELTING OF LEAD ORE, AS PRACTISED IN DERBYSHIRE.

THERE is a certain ſtandard of perfection in the exerciſe of every art, which is not always well underſtood; and after men do ſufficiently comprehend it, many ages often paſs away before they are fortunate or ingenious enough to attain it. To extract the greateſt poſſible quantity of metal, from any particular kind, and any definite quantity of ore, is a problem of great importance, whether it be conſidered in a philoſophical or a commercial light; yet he who ſhould apply himſelf to the ſolution of it, with an expectation of being uſeful to mankind, muſt take into conſideration another circumſtance, of as much importance as the quantity of metal to be extracted,—the expence attending the proceſs. For it is obvious, that a great quantity of metal extracted at a great expence, may not produec ſo much clear profit, as a leſs quantity procured at an eaſier rate; there is a beneficial limit between the quantity to be obtained, and the expence attending the operation, which nothing but experience can aſcertain.

It has been proved, by experiments made in *France*, * that lead ore when ſmelted by a fire made of wood, yielded one tenth more lead, than in the ordinary method of ſmelting by means of pitcoal; yet pitcoal is ſo much cheaper than wood, in Derbyſhire, and moſt other parts of Great Britain, that the loſs of a tenth of the lead, is probably, more than compenſated, by the uſe of pitcoal inſtead of wood or charcoal. It is poſſible, perhaps, even with the uſe of pitcoal, by an alteration in the proceſs of ſmelting, to extract from every twenty tons of ore, one ton more of lead than is any where extracted at preſent; but whether the price of one ton of lead, would be more than ſufficient to defray the extraordinary expence attending the alteration of the proceſs, muſt be left to the deciſion of thoſe who are intereſted in the ſucceſs of ſuch inquiries.

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* Eſſais des Mines, par M. Hellot, Vol. II. p. 114.

The art of ſmelting the ores of all metallic ſubſtances, was, probably, at firſt very imperfect in every part of the world; and this doubtleſs has been a reaſon, why the uſe of iron has every where been of a more recent date, than that of the other metals, ſince it requires the application of a much ſtronger fire to ſmelt the ores of iron, than thoſe of any other metal.

We have no certain account when, or by whom, the ſeveral metals were diſcovered; *Wallerius* ſays, that, as far as he knew, *Pliny* was the firſt who enumerated the *ſix metals:*[*] Pliny may, probably, be the firſt Natural Hiſtorian who mentioned them, but they were certainly known long before the age of Pliny, and were mentioned both by *Homer*, and by an author far more ancient than Homer—*Moſes*.—"Only the *gold*, and the *ſilver*, the braſs (*copper*), the *iron*, the *tin*, and the *lead*, every thing that may abide the fire, ye ſhall make it go through the fire, and it ſhall be clean."[†] From this teſtimony we are certain that all the metals were known, at leaſt in the country of the *Midianites*, above 1450 years before the birth of Chriſt, or near 900 years after the deluge. When I ſay all the metals, I muſt be underſtood to mean, all thoſe which were anciently known; for *platina*, the ſeventh metal, has been but recently diſcovered, and is not yet brought into general uſe; and *quickſilver* or *mercury* is not admitted by mineralogiſts into the claſs of metals; though it has a good right to be admitted, ſince in a ſufficient degree of cold, it poſſeſſes the great characteriſtic property of a *metal*, as diſtinguiſhed from a *ſemi-metal—malleability*. This property of malleability, as conſtituting the criterion by which metals differ from ſemimetals, is not over rigidly to be inſiſted on, ſince iron, when firſt fluxed from its ore, or when converted into ſteel, and hardened by being ſuddenly immerſed when red hot in water, is leſs malleable than *zinc*, which is always claſſed amongſt the ſemimetals.

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[*] —Primus (ſcil Plinius) quantum mihi conſtat, ſex metalla enumeravit. Waller, de Syſ. Minera. p. 10.

[†] Numb. xxxi. 22.

It has been contended, that copper was one of the firſt metals which was uſed as money, and that gold and ſilver were, in very remote ages, of little account in that view. In many inſtances the greatneſs of the *Roman* name has made us forget the æra when that people began to be diſtinguiſhed in hiſtory, and induced us to conſider their cuſtoms, as the firſt which prevailed amongſt mankind. It is granted, that *Servius Tullius* firſt coined copper, and that the Romans uſed no other currency till the four hundredth and eighty-fifth year of their city,* when ſilver began to be coined; but from this conceſſion, no argument can be deduced for the ſole uſe of copper as a currency, in the firſt ages of the world. We know, from undoubted authority, that ſilver was uſed in commerce, at leaſt eleven hundred years before even the foundation of Rome. — *And Abraham weighed to Ephron, the ſilver which he had named in the audience of the ſons of Heth, four hundred ſhekels of ſilver, current money with the merchant**. About 60 years before Abraham paid this ſum for a piece of land in *Canaan*, he is ſaid, upon his return from *Egypt*, to have been rich, not in copper and iron, but in ſilver and gold †.

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* Plin. Hiſt. Nat. Lib. XXXIII. S. 13.

Iron and copper were certainly known before the deluge; and it is probable, that all the other metals, every one of which is more eaſily extracted from its ore than iron and copper are from their's, were known alſo to the Antediluvians; we have proof, however, that in the time of Abraham, gold and ſilver were eſteemed, as they are at preſent, precious metals; and hence it ſeems reaſonable enough to conclude, that *Noah* was able to inſtruct his deſcendants in the art of ſmelting metallic ores: but, though this be admitted, we need not be ſurprized at the ignorance of many barbarous nations in this particular. For the various colonies which, either by compulſion or choice, quitted the plains of *Aſia*, in ſearch of ſettlements, may not always have had in their company men who had been inſtructed in the art of ſmelting; and thoſe who did underſtand it, when the colony firſt migrated, may, in many inſtances, have died before any ores were diſcovered, upon which they might have exerted their ſkill; and thus the art of ſmelting being once loſt, it is eaſy to conceive that many nations may have remained for ages without the uſe of metals, or with the uſe of ſuch only as are found ready formed in the earth, or are eaſily fluxed from their ores.

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* Gen. xxiii. 16.

† Gen. xiii. 2.

The earth in a little time after the deluge, and long before it could have been peopled by the poſterity of Noah, muſt have become covered with wood; the moſt obvious method of clearing a country of its wood, is the ſetting it on fire: now in moſt mineral countries there are veins of metallic ores, which lie contiguous to the ſurface of the earth, and theſe having been fluxed whilſt the woods growing over them were on fire, probably, ſuggeſted to many nations the firſt idea of ſmelting ores.

——Pow'rful gold firſt raiſed his head,
And braſs, and ſilver, and ignoble lead.
When ſhady woods, on lofty mountains grown,
Felt ſcorching fires; whether from thunder
thrown,
Or elſe by man's deſign the flames aroſe.

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Whatever 'twas that gave theſe flames their
birth,
Which burnt the towering trees and ſcorch'd
the earth,
Hot ſtreams of ſilver, gold, and lead, and
braſs, (copper)
As nature gave a hollow proper place,
Deſcended down, and form'd a glitt'ring
maſs *.

There

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* Lucretius by Creech, Vol. II. p. 572.

There is no natural abſurdity in this notion of the poet; and indeed it is confirmed by the teſtimony of various ancient hiſtorians, who ſpeak of ſilver and other metals being melted out of the earth, during the burning of the woods upon the *Alps* and the *Pyrenees*. A ſimilar circumſtance is ſaid to have happened in *Croatia* in the year 1761; a large maſs of a mixed metal, compoſed of copper, iron, tin and ſilver, having been fluxed, during the conflagration of a wood, which was accidentally ſet on fire. *

The putting a quantity of ore upon a heap of wood, and ſetting the pile on fire, in conformity to the manner in which ores were melted during the burning of foreſts was, it may be conjectured, the firſt rude proceſs by which metals were extracted from their ores. But as the force of fire is greatly diminiſhed, when the flame is ſuffered to expand itſelf, and as the air acts more forcibly in exciting fire, when it ruſhes upon it with greater velocity, it is likely, that the heap of wood and ore would ſoon be ſurrounded with a wall of ſtone, in which ſufficient openings would be left for the entrance of the air, and thus a kind of furnace would be conſtructed. The *Peruvians* we are told "had diſcovered the art of ſmelting and refining ſilver, either by the ſimple application of fire, or where the ore was more ſtubborn and impregnated with foreign ſubſtances, by placing it in ſmall ovens or furnaces on high grounds, ſo artificially conſtructed that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted." *

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* Annual Regiſter, 1761, p. 138.

This method of ſmelting ores on high grounds, without the aſſiſtance of a bellows, at leaſt of a bellows moved by water, ſeems to have been formerly practiſed in other countries as well as in *Peru*. When *M. Belon* travelled into *Greece*, he found the furnaces placed on the ſides of rivulets, and obſerves, that all their bellows played with wheels turned by ſtreams of water, yet formerly they had ſmelted their ores in a different manner: for upon the mountains of *Macedonia*, where mines had been wrought in the time of *Philip* the father of *Alexander*, great heaps of ſlag have been diſcovered, which are ſituated ſo far above any river of the country, that the furnaces from which they were formed, muſt, probably, have been wrought by the wind. There are ſeveral places in *Derbyſhire* called *Boles* by the inhabitants, where lead has been anciently ſmelted, before the invention of moving bellows by water. Theſe places are diſcovered by the ſlags of lead, which are found near them; there is no certain tradition concerning the manner in which the ore was ſmelted at theſe boles, it was, probably, as ſimple as that of the *Peruvians*; for in *Derbyſhire*, as well as in *Peru*, they ſeem chiefly to have relied upon the ſtrength of the wind for the ſucceſs of the operation; the boles being always ſituated upon high grounds, and moſtly upon that ſide of a hill, which faces the weſt. This ſituation was not fixed upon without deſign, ſince the wind blows in England, in the courſe of a year, near twice as many days from that quarter as from any other.* A method is mentioned by *Erckern* † of ſmelting biſmuth ore by the wind, and it ſeems as if the ore of lead might have been ſmelted at theſe boles,

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* Robertſon's Hiſt. of America.—Alonſo Barba, Treatiſe of Metals, French Tranſ. Vol. I. p. 272.

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* As may appear from the following abridged ſtate of the winds at London in the years 1774 and 1775.

	N	S	E	W	NW	SE	NE	SW	
1774	25	21	17½	24	43½	30	74	126½	dys.
1775	22½	21½	11	18½	39½	32½	72	148	

Philoſ. Tranſ. 1774---5.

† See Fleta Minor. by Sir John Pettus. p. 305.

boles, after the ſame manner. This method conſiſts in putting the biſmuth ore, when beat to a proper ſize, into ſmall flat iron pans, theſe are ſet in a row contiguous to each other, in an open place; and when there is a ſtrong wind, a fire of dry wood is made cloſe to the pans, and on that ſide of them from which the wind blows, by this contrivance, the wind driving down the flame of the wood upon the pans, the ore contained in them is quickly melted. A pig of lead was dug up at one of the boles in the year 1766 on *Cromford* moor near *Matlock*, upon its under ſurface there is an inſcription in *relievo*, from which it appears to have been ſmelted in the age of the Emperor *Adrian*; it is not very different in ſhape from the pigs which are caſt at preſent; it conſiſts of ſeveral horizontal layers of unequal thickneſſes, and there is an irregular hole in it running from the top to near the middle of its ſubſtance; from theſe appearances it ſeems as if it had been formed by pouring into a mould, at different times, ſeveral quantities of lead; and if lead had been ſmelted after the manner before mentioned of ſmelting biſmuth ore, the ſeveral pans being emptied, at different times as they became ready, into the ſame mould, would have yielded a maſs of lead divided into layers of unequal thickneſſes, and reſembling this Roman pig; for the hole in its ſurface was, probably, made accidentally, from the unequal cooling of the lead, or from ſome extraneous matter being lodged in it.

The boles in Derbyſhire are, probably, many of them of high antiquity, as appears from the pig of lead before mentioned; yet I have met with a paſſage in a writer of the laſt century, from which it is evident, that the method of ſmelting lead on high grounds was then practiſed in the Peak.. "The lead-ſtones in the Peak lye but juſt within the ground next to the upper cruſt of the earth. They melt the lead upon the top of the hills that lye open to the weſt wind; making their fires to melt it as ſoon as the weſt wind begins to blow; which wind by long experience they find holds longeſt of all others. But, for what reaſon I know not, ſince I ſhould think lead were the eaſieſt of all metals to melt, they make their fires extraordinary great." *

The ſmelting of ore by the variable and uncertain action of the wind, muſt have been a troubleſome proceſs. It has therefore been univerſally diſuſed, and the more regular blaſt of a bellows has been introduced in its ſtead. The invention of the bellows is attributed by *Strabo* to *Anacharſis* the Scythian: † but it is more probable, that he was the inventor of ſome improvement of this machine, than of the machine itſelf; for *Homer*, who lived long before the age of *Anacharſis*, deſcribes *Vulcan* as employing twenty pair of bellows at once, in the formation of *Achilles*'s ſhield.* It is difficult to ſay when the art of moving bellows, by means of a water wheel, was firſt diſcovered; it is pretty certain, that the ancients did not know it; and that it was very generally known, amongſt the Germans at leaſt, in the time of Agricola, one of the firſt of our metallurgic writers, for he ſpeaks of it in ſeveral places without any hint of its being a recent invention.† The heat of the fire in a furnace depending much upon the force of the blaſt of air impelled againſt the fuel; and that force, other circumſtances remaining the ſame, being in proportion to the quantity and velocity of the air; the application of a power able ſuddenly to compreſs the largeſt bellows when ſwelled with air, could not fail of being conſidered by metallurgiſts, as an invention, whenever it was made, of the laſt importance. The moderns accordingly have, in many inſtances, worked over again, with conſiderable profit, the heaps of iron and other kinds of ſlag, from which the metal had been but imperfectly extracted, before the moving of bellows by water was diſcovered.

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* Childrey's Britan. Bacon. 1661.
† Strab. Geog. Lib. VII.

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* Iliad. Lib. XVIII. v. 470.

† Agric. de Re Metal. publiſhed in 1550, p. 165. 338.

It is not fifty years ſince the *blaſt* or *hearth* furnace, was the only one in uſe for ſmelting lead ore in *Derbyſhire*. In this furnace ore and charcoal, or ore and what they call white coal, which is wood dried but not charred, being placed in alternate layers, upon a hearth properly conſtructed, the fire is raiſed by the blaſt of a bellows, moved by a water wheel; the ore is ſoon ſmelted by the violence of the fire, and the lead as it is produced trickles down a proper channel, into a place contrived for its reception. There are not at preſent, I believe, above one or two of theſe *ore hearths* in the whole county of Derby; this kind of furnace, however, is not likely to go entirely out of uſe, ſince it is frequently applied to the extracting lead from the *ſlag* which is produced, either at the *ore hearth*, or the *cupola* furnace, and it is then called a *ſlag hearth*; and the lead thus obtained is called *ſlag lead:* the fire in a ſlag hearth is made of the cinder of pitcoal inſtead of charcoal.

The furnace called a *cupol* or *cupola*,

pola, in which ores are ſmelted by the flame of pitcoal, is ſaid to have been invented, about the year 1698, by a phyſician named *Wright*, * though Beecher may, perhaps, be thought to have a prior claim to its invention or introduction from Germany. † But whoever was the firſt inventor of the cupola, it is now in general uſe, not only in Derbyſhire and other countries for the ſmelting of the ores of lead, but both at home and abroad, where it is called the Engliſh furnace, for the ſmelting of copper ores. This furnace is ſo contrived, that the ore is melted, not by coming into immediate contact with the fuel, but by the reverberation of the flame upon it. The bottom of the furnace on which the lead ore is placed, is ſomewhat concave, ſhelving from the ſides towards the middle; its roof is low and arched, reſembling the roof of a baker's oven; the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free acceſs; at the other end, oppoſite to the fire place, is a high perpendicular chimney; the direction of the flame, when all the apertures in the ſides of the furnace are cloſed up, is neceſſarily determined, by the ſtream of air which enters at the grate, towards the chimney, and in tending thither it ſtrikes upon the roof of the furnace, and being reverberated from thence upon the ore, it ſoon melts it.

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* Eſſais des Mines, Vol. II. p. 114.

† See Vol. I. p. 33.

It is not always an eaſy matter to meet with a current of water, ſufficient to move the bellows required in ſmelting on an hearth furnace; and to carry the ore from the mine where it is dug, to a conſiderable diſtance to be ſmelted, is attended with great expence; this expence is ſaved by ſmelting in the cupola furnace, which not requiring the uſe of bellows, may be conſtructed any where. Wood is very ſcarce in every mining country in England, and though pitcoal coſts ten or twelve ſhillings a ton in Derbyſhire, yet they can ſmelt a definite quantity of ore in the cupola, at a far leſs expence by means of pitcoal, than of wood.—The flame which plays upon the ſurface of the ore and ſmelts it in a cupola furnace, is not driven againſt it with much violence; by this means ſmall particles of ore, called *belland*, may be ſmelted in a cupola furnace with great convenience, which would be driven away, if expoſed to the fierce blaſt of a pair of bellows in a hearth furnace.—Theſe are ſome of the advantages attending the uſe of a cupola in preference to a hearth furnace; and to theſe may be added one ſuperior to all the reſt,—the preſervation of the workmen's lives; the noxious particles of lead are carried up the chimney in a cupola, whilſt they are driven in the face of the hearth ſmelter at every blaſt of the bellows.

They generally put into the cupola furnace a ton of ore, previouſly beat ſmall and properly dreſſed, at one time; this quantity they call a *charge*; if the ore is very poor in lead they put in ſomewhat more, and they work off three charges of ore in every twenty-four hours. In about ſix hours from the time of charging, the ore becomes as fluid as milk. Before the ore becomes fluid, and even whilſt it continues in a ſtate of fuſion, a conſiderable portion of its weight is carried off through the chimney; what remains in the furnace conſiſts of two different ſubſtances,—of the lead, for the obtaining of which the proceſs was commenced,—and of the *ſlag* or *ſcoria*. The proportion between theſe parts is not always the ſame, even in the ſame kind of ore; it depending much upon the management of the fire. The lead, being heavier than the ſlag, ſinks through it as it is formed, and ſettles into the concavity of the bottom of the furnace. The pure ſlag, according to the idea here given, is that part of the ore of lead which is neither driven off by the heat of the furnace, nor changed into lead. In order to obtain the lead free from the ſlag which ſwims over it, the ſmelters uſually throw in about a buſhel of lime; not, as is uſually ſuppoſed, in order to contribute towards the more perfect fuſion of the ore, but to dry up the ſlag which floats upon the ſurface of the lead, and which, being as liquid as lead, might otherwiſe flow out along with it. The ſlag being thus thickened by an admixture of lime, is raked up towards the ſides of the furnace, and the lead is left at the bottom. There is a hole in one of the ſides of the furnace, which is properly ſtopped during the ſmelting of the ore; when the ſlag is raked off, this hole is opened, and being ſituated lower than the lead in the furnace, the lead guſhes through it into an iron pot placed contiguous to the ſide of the furnace; from this pot it is laded into iron moulds, each containing what they call a pig of lead, the pigs when cold, being ordinarily ſtamped with the maker's name, are ſold under the name of *ore lead*. After the lead has all flowed out of the furnace, they ſtop up the tap hole, and drawing down the ſlag and lime into the middle of the furnace, they raiſe the fire till the mixture of ſlag and lime, which they ſimply term ſlag, is rendered very liquid, upon this liquid maſs, they throw another quantity of lime to dry it up as in the former part of the proceſs. This ſecond mixture of ſlag and lime is then raked out of the furnace, and the ſmall portion of lead ſeparated from the fuſion of the firſt, generally to the amount of twenty or thirty pounds, being let out of the furnace, a new charge of ore is put in, and the operation re-commenced. In order to ſpare the lime, and the expence of fuel attending the fluxing of the mixture of lime and ſlag, they have in ſome furnaces lately contrived a hole, through which they ſuffer the main part of the liquid ſlag to flow out, before they tap the furnace for the lead; upon the little remaining ſlag they throw a ſmall portion of lime, and draw the mixture out of the furnace without ſmelting it. This kind of furnace they have nick-named a *Maccaroni.*

The proceſs of ſmelting here deſcribed, appears to be defective in ſome points, which I will take the liberty to mention, and at the ſame time ſuggeſt the means of improvement; without, however, preſuming to ſay, how far it may be expedient to adopt the propoſed alterations; being ſenſible that what may appear very feaſible in theory, or may even anſwer in ſmall aſſays, may not be practicable in large works.

The firſt alteration which I would propoſe to the conſideration of the lead ſmelters, is to ſubſtitute an horizontal chimney of two or three hundred yards in length, in the place of the perpendicular one now in uſe. In the preceding Eſſay, which was firſt publiſhed in 1778, mention is made of the probability of ſaving a large quantity of ſublimed lead, by making the ſmoke, which riſes from the ore, paſs through an horizontal chimney, with various windings to condenſe the vapour. I have ſince converſed with ſome of the principal lead ſmelters in *Derbyſhire*, and find that I had over-rated the quantity of this ſublimed lead; the weight of the *ſcoria* from a ton of ore, amounting to more than I had ſuppoſed; they were all of them, however, of opinion, that the plan I had propoſed for ſaving the ſublimate, was a very rational one. But ſo difficult is it to wean artiſts from their ancient ways of operating, that I queſtion very much whether any of them would ever have adopted the plan they approved, if an horizontal chimney, which was built a little time ago in *Middleton dale*, for a quite different purpoſe, had not given them a full proof of the practicability of ſaving the ſublimate of lead, which is loſt in the ordinary method of ſmelting. This chimney was built on the ſide of an hill, to prevent ſome adjoining paſtures from being injured by the ſmoke of the furnace. It not only anſwers that end, but it is found alſo to collect conſiderable quantities of the lead, which is ſublimed during the ſmelting of the ore; this ſublimed lead is of a whitiſh caſt, and is ſold to the painters at ten or twelve pounds a ton; it might perhaps be converted into red lead with ſtill more profit.

A ſecond circumſtance to be attended to in the ſmelting of lead ore, is the ſaving the ſulphur contained in it. The pure lead ore of Derbyſhire contains, between an eighth and a ninth part of its weight of ſulphur; but as the ore which is ſmelted is never pure, being mixed with particles of *ſpar*, *cawk*, *limeſtone*, *brazil*, and other ſubſtances, which the miners call *deads*, we ſhall be high enough in our ſuppoſition, if we ſay that the ordinary ore contains a tenth of its weight of ſulphur; it may not, probably, contain ſo much, but even a twelfth part, could it be collected at a ſmall expence, would be an object of great importance to the ſmelter. In the common method of ſmelting lead ore there is no appearance of the ſulphur it contains, it is conſumed by the flame of the furnace, as ſoon as it is ſeparated from the ore; an attentive obſerver may, indeed, by looking into the furnace diſtinguiſh a diverſity in the colour of the flame, at different periods of the proceſs; during the firſt three or four hours after the ore is put into the furnace, the flame has a bluiſh tint, proceeding no doubt from the ſulphur which, in being ſublimed from the ore, is inflamed: after all the ſulphur is ſeparated from the ore, the flame has a whitiſh caſt, and then and not before the fire may be raiſed for finiſhing the operation; for if the fire be made ſtrong before the ſulphur be diſperſed, the quantity of lead is leſs, probably, for two reaſons; the ſulphur unites itſelf in part to the lead which is formed, and by this union becomes inſeparable from it; for the ſulphur cannot without much difficulty be ſeparated from an artificial mixture of lead and ſulphur, when the two ingredients have been fuſed together;—2. The ſulphur, whilſt it continues united to the lead in the natural ore, renders the ore volatile, ſo that in a ſtrong heat a great portion of it is driven off. Hence, very ſulphureous ores ſhould be roaſted for a long time with a gentle heat, and in this proper management of the fire, principally conſiſts the ſuperiority of one ſmelter above another.

An old lead ſmelter informed me that he had often reduced a ton of ore to 16 hundred weight by roaſting it, but that he did not obtain more metal from it by a ſubſequent fuſion, than if he had fluxed it without a previous roaſting. This may be true of ſome ſorts of ore, but it is not true of very ſulphureous ores. Indeed the fire may be ſo regulated in a cupola furnace, as to make it anſwer the purpoſe of a roaſting and a ſmelting furnace at the ſame time: I have ſeen much lead loſt by ſmelting a ton of ſulphureous ore in eight hours, which might have been ſaved, if the fire had at firſt been kept ſo gentle as to have allowed twelve hours for finiſhing the operation.

Sulphur cannot be ſeparated from lead ore in cloſe veſſels, and the lead ore melts with ſo ſmall a degree of heat, that there may be more difficulty in procuring the ſulphur from the ores of lead, than from thoſe of copper or iron, however, I am far from thinking the matter impracticable, though I have not yet hit upon the method of doing it; and the following reflections may, perhaps, tend to ſuperſede the neceſſity of collecting the ſulphur in ſubſtance.

When it is ſaid that the ſulphur is conſumed by the flame of the furnace as ſoon as it is ſeparated from the ore, the reader will pleaſe to recollect, that ſulphur conſiſts of two parts, — of an inflammable part by which it is rendered combuſtible, — and of an acid part which is ſet at liberty, in the form of vapour, during the burning of the ſulphur. Now this acid, though it may be driven out of the furnace in the form of a vapour, yet it is incapable of being thereby decompoſed; it ſtill continues to be an acid; and, could the vapour be condenſed, might anſwer all the ſame purpoſes as the acid of vitriol; ſince all the acid of vitriol, now uſed in commerce, is actually procured from the burning of ſulphur. That the fact, with reſpect to the acid not being decompoſed, is as I have ſtated it, may be readily proved. The ſmoke which iſſues out of the chimney for ſome hours after each freſh charge of ore has a ſuffocating ſmell, perfectly reſembling the ſmell of burning brimſtone, and if a wet cloth, or a wet hand be held in it for a very ſhort ſpace of time, and afterwards applied to the tongue, a ſtrong acid will be ſenſibly perceived. Various methods may be invented for condenſing this acid vapour, and, probably, more commodious than the following one, which, however, I will juſt take the liberty of mentioning, as, if it ſhould not ſucceed, the trial will be attended with very little expence.

Suppoſing then an horizontal chimney to be built, let the end fartheſt from the fire be turned up by a tube of earthen ware, or otherwiſe, ſo that the ſulphureous acid may iſſue out in a direction parellel to the flue of the chimney, and at the diſtance of about a foot and an half above it. Let a number of large globular veſſels be made of either glaſs or lead, each of theſe globes muſt have two necks ſo as to be capable of being inſerted into one another; let theſe veſſels be placed on the flue of the chimney, the neck of the firſt being inſerted into the tube through which we have ſuppoſed the ſulphureous acid to iſſue, and the neck of the laſt being left open, for fear of injuring the draught of the furnace. Let each of theſe globular veſſels contain a ſmall quantity of water, then it is conceived, that the heat of the flue will raiſe the water into vapour, and that this watery vapour will be the means of condenſing the ſulphureous acid vapour, if not wholly, at leaſt in ſuch a degree as may render the undertaking profitable. When the ſulphur is all conſumed, the draught of the furnace may be ſuffered to have its ordinary exit at the end of the horizontal chimney, by a very ſlight contrivance of a moveable damper. Since the firſt publication of the preceding Eſſay, I have ſeen an horizontal chimney at the copper works near Liverpool, where every thing I had ſaid concerning the probability of ſaving ſulphur by roaſting lead ore, is verified with reſpect to copper ore : and I believe a patent has been granted to ſome individual for this mode of collecting ſulphur. Sulphur might be obtained with equal facility from the *pyrites* which is found amongſt coal, and this application of the pyrites might, probably, be more lucrative than the preſent one—making green vitriol.*

A third circumſtance, which requires the utmoſt care of the lead ſmelter, is the leaving as little lead as poſſible in the ſlag. Near every ſmelting houſe there are thouſands of tons of ſlag, which, when properly

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* Vol. I. p. 229.

aſſayed, are found to yield from one eighth to one tenth of their weight of lead; though no perſon has yet diſcovered a method of extracting ſo much from them when ſmelted in large quantities; and indeed the ſmelters are ſo little able to obtain all the lead contained in them, that in many places they never attempt to extract any part of it: in ſome places, where they do attempt it, I have known the proprietor of the ſlag allow the ſmelters 20s. for every pig of lead they procured of the value of 38s. beſides furniſhing them with fuel; and yet the men employed in ſuch an unwholeſome buſineſs, ſeldom made above 7s. a week of their labour. This fuſion of the ſlag of a cupola furnace is made, as has been mentioned, at a hearth furnace;

nace; the coal cinder, which they uſe as fuel, and the ſlag are ſoon melted by the ſtrong blaſt of the bellows into a black maſs, which, when the fire is very ſtrong, becomes a perfect glaſs; this black maſs, even in its moſt liquid ſtate, is very tenacious, and hinders many of the particles of lead from ſubſiding, and it being from time to time removed from the furnace, a conſiderable quantity of lead is left in it, and thereby loſt. A principal part of the lead contained in the ſlag of the cupola furnace, is not, I apprehend, in the form of a metal, but in the form of a litharge or calcined lead: a portion of the lead, in being ſmelted from its ore, is calcined by the violence of the fire; this calcined lead is not only very vitrifiable of itſelf, but it helps to vitrify the ſpar which is mixed with the ore, and thus conſtitutes the liquid ſcoria; might it not be uſeful to throw a quantity of charcoal duſt upon the liquid ſcoria in the cupola furnace, in order that the calcined lead might be converted into lead, by uniting itſelf to the inflammable principle of the charcoal? — Iron will not unite with lead, but it readily unites with ſulphur, and when added to a mixture of lead and ſulphur, it will abſorb the ſulphur, leaving the lead in its metallic form; might it not be uſeful to flux ſulphureous lead ores in conjunction with the ſcales or other refuſe pieces of iron, or even with ſome ſorts of iron ore? —— The ſmelter's great care ſhould be to extract as much lead as poſſible at the firſt operation of ſmelting the ore, and to leave the ſlag as poor as poſſible; but if he ſhould ſtill find either the ſlag of the cupola furnace, or that of the hearth furnace, containing much lead, (as that even of the hearth furnace certainly does), he may, perhaps, find it worth his while to reduce the ſlag into a powder by a ſtamping mill, or by laying it in highways to be ground by the carts, or by ſome other contrivance, and then he may ſeparate the ſtony part of the ſlag from the metallic, by waſhing the whole in water, inaſmuch as the metallic part is far heavier than the other.

I eſtimated the weights of ſeveral pieces of ſlag, and found them to differ very much from each other; this difference is principally to be at-

attributed to the different quantities of lead left in them.

Weight of a cubic foot of

	Avoir. oz.
Slag from a cupola furnace, where no lime was uſed - - -	3742
Black ſlag from a hearth furnace -	3652
Another piece - - - - -	3612
Black ſlag from another hearth furnace --- ſtruck fire with ſteel	3378
Blaſs glaſs ſlag - - - - - -	3371

This may not be an improper place to add a word or two concerning the *Derbyſhire Toadſtone*, which conſtitutes one of the principal ſtrata in the mining country,* and which is ſuppoſed to have been in its origin a *ſlag* thrown out by a *volcano*. It perfectly reſembles ſome of the ſpecimens, I have ſeen, of one of the ſorts of the *lava* of *Veſuvius*, not only in the hardneſs of its texture, and blackneſs of its colour, but in its weight; a cubic foot of ſome ſorts of Derbyſhire toadſtone weighing more, and of other leſs than a cubic foot of the Veſuvian lava, which it reſembles. The ſtreets of *London* have ſome of them been paved, of late years, with a *toadſtone* from *Scotland*, of the ſame nature as the Derbyſhire toadſtone; and the ſtreets of *Naples* have for many centuries paſt, been paved with the lava from Veſuvius which reſembles toadſtone. Neither the Derbyſhire toadſtone, nor that ſort of Veſuvian lava which reſembles it, ſeem to have experienced in their formation any great degree of heat, they are but in a half vitrified ſtate; the toad-ſtone I have frequently melted in a ſmith's forge into a black glaſs, and the Veſuvian lava gives a glaſs of the ſame kind. The air has a manifeſt action upon the Derbyſhire toadſtone, for it not only waſtes away the ſpar which is found in the blebs of ſome ſorts of toadſtone, but it reduces into a browniſh mould, fit for vegetation, the moſt hard and compact ſorts; the Veſuvian lava is ſubject to the ſame change from the operation of the ſame cauſe.

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* See Vol. II. p. 206.

Weight of a cubic foot of	Avoir. oz.
Toadſtone hard and free from blebs	2884
Veſuvian lava reſembling toadſtone	2865
Iron ſlag, a greeniſh glaſs - - - - -	2843
Iron ſlag, a browniſh glaſs - - - -	2729
Iceland cryſtal ---- Mr. Cotes - - -	2720
Toadſtone, decaying - - - - - - -	2680
Another piece - - - - - - - - - -	2662
Another piece - - - - - - - - - -	2558

ESSAY IX.

OF SILVER EXTRACTED FROM LEAD.

WE have no ſilver mines, properly ſpeaking, in *Great Britain*, but we have plenty of lead, from which ſilver is, in ſome places, extracted with much profit. If the method of doing this had been known to the ancient *Britons*, it might have freed our country from the reproach of *Cicero*, who tells his friend *Atticus*, that there was not a ſcruple of ſilver in the whole iſland;* and in another place, he ſays, that he had heard there was neither gold nor ſilver in *Britain*. † The *Romans* had a very imperfect knowledge of this country in the time of *Cicero*, ſo that his account of the matter may not, perhaps, deſerve to be much relied on; we are certain, at leaſt, that about fifty or ſixty years afterwards, both gold and ſilver were reckoned by *Strabo* amongſt the products of *Britain*; ‡ hence, if the Britons did not underſtand the art of extracting ſilver from lead at the firſt invaſion of the Romans, they ſoon learned it from their conquerors; and this becomes more probable, if it be admitted, that ſilver was coined in Britain in the time of *Auguſtus*.*

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* ------ etiam illud jam cognitum eſt, neque argenti ſcrupulum eſſe ullum in illa inſula (Britann.) Epiſt. ad Att. L. IV. E. XVII.

† Epiſt. Fam. L. VII. E. VII.

‡ L. IV. p. 305. --- See alſo Tacitus' Life of Agricola.

Silver is ſo commonly contained in lead, that it is eſteemed a very great curioſity to meet with lead which is entirely free from it: it has even been aſſerted, that there is no lead in the world, except that of *Villach* in *Carinthia*, which does not contain ſilver. †

The more ancient alchemiſts, not knowing, probably, that ſilver was ſo generally contained in lead, and yet obſerving, that lead, when treated according to their proceſſes, often gave a portion of ſilver, were of opinion, that they could convert lead into ſilver.* This was an eaſy miſtake, and if they had obtained a portion of gold, they would, no doubt, have concluded, that they had tranſmuted the lead into gold; ſince there is no metal, perhaps, which does not *contain* a ſmall quantity of gold, or from which gold may not be *ſeparated* by long calcination.

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* Sir John Pettus Fod Reg.

† Il n'y point de plomb au monde, hormis celui de Villach que ne contienne de l' argent. Lehman ſur les Mines, Vol. I. p. 174. ----See alſo Philoſ. Tranſ. for 1665. p. 10.

Liſter had long ago obſerved, that all the Engliſh lead contained ſilver; and he ſpeaks as having, by his own experiments, proved the exiſtence of ſilver in the lead of at leaſt thirty different mines; † nor has any perſon

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* Gebri Chem. L. I. C. XIX.

† Liſter de Fontibus, Cap. II. S. 9, 10.

ſon ſince his time, found lead wholly free from ſilver. The *Derbyſhire* lead has been ſaid to contain two grains of ſilver in a pound of lead.* Every general obſervation of this kind is liable to much contravention from particular facts; becauſe the quantity of ſilver contained in lead, is not only different according as the lead is fluxed from the ore of different mines, but it is very poſſible in an aſſay of the ore of the ſame mine, to meet with one piece of ore which ſhall afford a lead yielding eight or ten times as much ſilver, as another piece would do. This diverſity ariſes from the ore itſelf being variable in quality in different parts of the ſame mine; and even different lumps of ore, though contiguous to each other, will yet obſerving, that lead, when treated according to their proceſſes, often gave a portion of ſilver, were of opinion, that they could convert lead into ſilver.* This was an eaſy miſtake, and if they had obtained a portion of gold, they would, no doubt, have concluded, that they had tranſmuted the lead into gold; ſince there is no metal, perhaps, which does not *contain* a ſmall quantity of gold, or from which gold may not be *ſeparated* by long calcination.

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* Oper. Min. Explicata, p. 263.

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* Oper. Min. Explicata, p. 263.

I have been informed by an intelligent perſon, that there are ſome lead ores in Great Britain, which, though very poor in lead, contain between three and four hundred ounces of ſilver in a ton of the lead. It is not to be expected that the proprietors of theſe, or of any other mines rich in ſilver, ſhould be forward in declaring to the world the quantity of ſilver which they contain. The proprietor indeed of a lead mine containing ſilver, may work the ſame, without any apprehenſion of its being taken from him, under the pretence of its being a *royal mine*; yet the crown, and perſons claiming under it, have the right of pre-emption, of all the ore which may be raiſed. There was an act of parliament paſſed in the ſixth year of *William* and *Mary*, intitled,—An act to prevent diſputes and controverſies concerning royal mines.—This act gave great quiet to the ſubject by declaring, that every proprietor of a mine of copper, tin, iron, or lead, ſhould continue in poſſeſſion of the ſaid mine, notwithſtanding its being claimed as a royal mine, from its containing gold or ſilver: but it further enacted, that their majeſties, their heirs and ſucceſſors, and all claiming under them, ſhould have the privilege of purchaſing all the ore which ſhould be raiſed out of ſuch a mine, at the following prices; this is to ſay, paying for all ore waſhed, made clean and merchantable, wherein is copper, after the rate of ſixteen pounds a ton; for tin ore (except that raiſed in Devonſhire and Cornwall) forty ſhillings; for iron ore forty ſhillings; and for lead ore nine pounds a ton. This ſtandard price of nine pounds a ton for lead ore was, at the time it was fixed, much higher than the ordinary price of ore, in which there was no ſilver worth extracting; the beſt kind of Derbyſhire lead ore, being at preſent, generally worth no more than ſeven pounds a ton. It may deſerve however the conſideration of the legiſlature, whether the clauſe in the forementioned act reſpecting the right of pre-emption ſhould not be wholly repealed; as there may be many lead mines in England very rich in ſilver, but which, on account of the difficulty of working them, cannot be entered upon with advantage, whilſt this right ſubſiſts. At many lead mines, moreover, there are large quantities of ſteel-grained ore raiſed together with the ordinary ſort, now it generally happens that the ſteel-grained ore is much richer in ſilver than the ordinary diced ore of Derbyſhire; and it might, if ſeparated from the reſt, be worked for ſilver; but whether from an apprehenſion of the operation of the clauſe we are ſpeaking of, or from mere ignorance or inattention, all the ſorts of ore are mixed and ſmelted together.

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* Some Account of Mines, p. 27.

Silver has formerly been extracted from lead in a great many places in this iſland. In the reign of Edward I. near 1600 pounds weight was obtained, in the courſe of three years, from a mine in *Devonſhire*, which had been diſcovered towards the beginning of his reign; this mine is called a ſilver mine by the old writers, but it appears to have been a mine of lead which contained ſilver.* The lead mines in *Cardiganſhire* have at different periods afforded great quantities of ſilver: Sir *Hugh Middleton* is ſaid to have cleared from them two thouſand pounds a month,* and to have been enabled thereby to undertake the great work of bringing the new river from *Ware* to *London*; and in alluſion, probably, to theſe two great circumſtances of his life, there are painted upon ſome of his pictures the two terms—*fontes*—*fodinæ*. Theſe ſame mines yielded, in the time of the great rebellion, eighty ounces of ſilver out of every ton of lead, and part of the king's army was paid with this ſilver, which was

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* Hollingſhed's Chron. Vol. II. p. 316. See alſo in the ſame author a further account of

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of ſilver extracted from the lead in Devonſhire and Cornwall in the time of Edward III. p. 413.

* Oper. Min. explic. p. 245.

was minted at *Shrewſbury*. † A mint for the coinage of Welch ſilver had before that time been eſtabliſhed in 1637 at *Aberyſtwith*; the indenture was granted to *Thomas Buſhel* for the coining of half-crowns, ſhillings, ſix-pences, two-pences, and pennies, and the monies were to be ſtamped with the oſtrich feathers on both ſides*. In the year 1604 near three thouſand ounces of this Welch bullion were minted, at one time, at the tower‡. *Webſter* in his hiſtory of metals, publiſhed in 1671, makes mention, from his own knowledge, of two places in *Craven*, in the weſt-riding of *Yorkſhire*, where formerly good ſilver ore (lead ore abounding in ſilver) had been gotten. One of the places was *Brunghill* moor in the pariſh of *Slaidburn*, the ore of which held about the value of ſixty-ſeven pounds of ſilver in a ton: the other was *Skelkorn* field within the townſhip of *Rimmington* in the pariſh of *Giſburn*; it had formerly belonged to one *Pudſey*, who is ſuppoſed to have coined the ſilver he got out of his mine, there being many ſhillings in that country which the common people called Pudſey's ſhillings.*

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† Sir J. Pettus, Eſſay on Metal. Works.

* Rym. Fæd. Tom. XX. 164.

‡ Some Account of Mines. p. 6.

There is not at preſent any place in *Derbyſhire* where ſilver is extracted from lead. A work of this kind was eſtabliſhed a few years ago not far from *Matlock*, and the lead yielded fourteen ounces of ſilver from a ton; but the mine which afforded the ore was ſoon exhauſted, or became too difficult to be worked with profit. There is a lead mine in *Patterdale* near *Keſwick*, which yields between fifty and ſixty ounces of ſilver from a ton of the lead, the ore of this mine is reckoned to be poor in lead; and indeed it is very commonly obſerved, that the pooreſt lead ores yield the moſt ſilver, ſo that much ſilver is probably thrown away, for want of having the ores of the pooreſt ſort properly aſſayed.

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* Webſter's Metal. p. 21.

The quantity of lead ſmelted annually in Derbyſhire, may be eſtimated at 7500 tons upon an average; fifty years ago the average was, probably 10000 tons a year, but we put it high enough in ſuppoſing it, at preſent, to amount to 7500 tons: I have never been able to get any proper information, concerning the quantity of lead annually ſmelted in other parts of Great Britain, but for the illuſtration of the ſubject we are upon, let us ſuppoſe that in the whole kingdom 30000 tons of lead are annually ſmelted, and that at a medium each ton of lead would yield 12 ounces of ſilver; then would there be, if all the lead was refined, a ſaving of three ounces of ſilver from each ton of lead, or ninety thouſand ounces in the whole; our Engliſh workmen reckoning that nine ounces of ſilver are full adequate to the expence of refining a ton of lead, added to that of the lead which is loſt during the operation.

The general manner of extracting ſilver from lead is every where the ſame; it is very ſimple, depending upon the different eſſential properties of the two metals.—It is an eſſential property of lead, when melted in the open air, to loſe its metallic appearance, and to burn away into a kind of earth.---It is an eſſential property of ſilver not to burn away, or to loſe its metallic appearance when expoſed to the action of the ſtrongeſt fires, in the open air. Hence, when a maſs of metal conſiſting of lead and ſilver, is melted in the open air, the lead will be burned to aſhes, and the ſilver remaining unaltered, it is eaſy to underſtand how the ſilver may be extracted from the lead; for being heavier than the aſhes of the lead, and incapable of mixing with them, (ſince no metal is miſcible with an earth), it will ſink to the bottom of the veſſel in which the maſs is melted. Iron, tin, and copper, reſemble lead, in being convertible into a kind of aſhes, when expoſed to the action of air and fire, and gold reſembles ſilver in not undergoing any change from ſuch action; hence either gold or ſilver, or a maſs conſiſting of both, may be purified from any or all of theſe metals by the mere operation of fuſion; for theſe metals will riſe to the top of the veſſel, in which the fuſion is made, in the form of an earth or droſs, leaving the gold or ſilver pure at the bottom.

The ancients certainly knew that ſilver could be purified from the baſe metals by the force of fire.--- *The houſe of Iſrael is to me become droſs: all they are braſs, (copper) and tin,*

*tin, and iron, and lead, in the midſt of the furnace; they are even the droſs of ſilver.** And as we read of ſilver being purified ſeven times in a furnace of earth, † it may, perhaps, be inferred, that the method of refining ſilver which was then in uſe, conſiſted in reducing the baſe metals into earth, by a repetition of the proceſs of fuſion. This inference, it muſt be owned, is rendered doubtful by a paſſage in *Jeremiah*;—*the bellows are burned, the lead is conſumed of the fire, the founder melteth in vain.*‡ ---This paſſage is ſomewhat ambiguous, and interpreters tranſlate the original Hebrew differently, but moſt of them collect from it, that the founder added lead to the mixed maſs which he wanted to refine.

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* Ezek. xxii. 18. † Pſ. xii. 6.
‡ Jerem. vi. 29.

Lead, when reduced to an earth by being burned in the open air, may, in a ſtronger degree of heat, be converted into a yellowiſh glaſs, * which

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* Other metallic ſubſtances yield coloured glaſſes, either when vitrified alone, or in conjunction with pure glaſs. In enamel and china painting they prepare roſe red and purple colours from gold; ſcarlet reds from iron, or vitriols that partake of it; greens from copper; blues from cobalt; blacks from magneſia, zaffer, and ſcales of iron; yellows from ſilver antimony, Naples yellow, and crocus martis; white from tin. The ſame ſubſtance yields different colours, according to the degree of heat to which it is expoſed; thus, the green colour of common glaſs bottles, which proceeds from the iron contained in the ſand and vegetable aſhes from which the glaſs is made, is changed into a blue by a ſtronger degree of heat.

which has the property of greatly contributing to the eaſy vitrification of all earthy ſubſtances; hence, when gold or ſilver are mixed with iron, copper, or tin, it is uſual to add to the mixed maſs a quantity of lead, in order to accelerate the purification; for the lead will be converted into glaſs, and this glaſs will vitrify all the extraneous ſubſtances with which the gold or ſilver are polluted, without exerting the leaſt action upon the precious metals themſelves.

I do not know upon what grounds one of the moſt diſtinguiſhed chemiſts of the age has aſſerted, "that the refining of gold and ſilver merely by the action of the fire was the only method anciently known;" † and founder added lead to the mixed maſs which he wanted to refine.

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† Chem. Dict. by M. Macquer. artic. Refining.

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and that the doing it by the addition of lead, is a diſcovery with which the ancients were unacquainted. Not to inſiſt upon what has been quoted from *Jeremiah*; in *Diodorus Siculus* there is a very minute deſcription of the manner of working ſome gold mines in the confines of *Egypt* and *Arabia*; this deſcription was probably written on the ſpot when he viſited that country, but the mode of operation ſeems to have been derived from a more early period; as the diſcovery of the mines is attributed by him to ſome of the moſt ancient *Ægyptian* kings; amongſt other particularities, he takes notice of their melting the mineral in conjunction with a little tin, ſome ſmall portion of ſalt, and a lump of *lead*.*

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* Diod. Sic. Lib. III. p. 183—189.

Strabo quotes *Polybius* as ſpeaking of a ſilver ore, which, after being five times waſhed, was melted with *lead*, and became pure ſilver. Unfortunately this part of the works of Polybius is loſt, or we might have had a more circumſtantial knowledge of the proceſſes by which the ancients extracted ſilver from its ores, as Strabo ſays, that he omitted Polybius' account of this matter, becauſe of its prolixity.† *Pliny* probably has an alluſion to the uſe of lead in refining ſilver, when he ſays, that a ſilver ore in the form of an earth could not be melted except in conjunction with lead or the ore of lead.* a more diligent ſearch into the writings of the ancients, would, doubtleſs,

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† Strab. Geo. Lib. II. p. 221.

* Plin. Hiſt. Nat. Lib. XXXIII. C. VI.

leſs, furniſh more authorities upon the point, but theſe may be ſufficient to induce us to believe, that they were not unacquainted with the uſe of lead in refining gold and ſilver.---But to return to the manner of extracting ſilver from lead.

The veſſel in which the workmen melt the maſs of ſilver and lead is of a ſhallow form, that a large ſurface of the melted maſs may be expoſed to the air, it is made uſually of four meaſures of the aſhes of calcined bones, and of one meaſure of unwaſhed fern aſhes, and is called a *teſt*.* This veſſel is very porous, but not ſo much as to imbibe the metal, whilſt it continues in the form of a metal; but as the earth, into which the lead is ſoon reduced by the action of the fire, becomes melted, the teſt imbibes a portion of it in that liquid ſtate, the other portion is driven off (as cream is blown off from milk) from the ſurface of the melted maſs, by the blaſt of a bellows. The liquid, half vitrified, earth of lead, which is thus driven off, concretes into hard maſſes of a ſcaly texture, and is called in that ſtate *litharge*, or ſilver ſtone, from the manner of its being produced, or from an idle notion of its containing

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* Teſts are ſometimes made of clay and other materials, and metallurgic writers often order the wood aſhes to be waſhed, leſt the alkaline ſalts which they contain ſhould tend to vitrify the teſt; but a very good refiner

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finer at Holywell informed me, that he always uſed the aſhes without waſhing them, as the veſſel became thereby leſs apt to crumble into pieces.

taining much ſilver. The litharge which is firſt formed is whitiſh, that which experiences a greater degree of heat is red; the colour of the litharge is alſo influenced by that of the other metals, which may chance to be mixed with the maſs of lead and ſilver. When the ſurface of the melted maſs becomes white, and throws up no more litharge, the operation is finiſhed; but as the remaining ſilver is not quite pure, ſince it contains a ſmall portion of lead, from which the degree of heat requiſite for melting the mixed maſs cannot readily free it, it is taken to a refining furnace, and rendered quite pure, at leaſt from lead, by *cupellation*. This proceſs conſiſts in melting the ſilver obtained from the firſt operation, in a veſſel made of the ſame materials as the teſt, and which, from its reſemblance to a wide mouthed cup, has been called a *cupel*. The cupel being expoſed to a ſtronger heat than the teſt, the lead which had eſcaped the action of the fire on the teſt, is now driven out from the ſilver, and being converted into litharge, is abſorbed by the cupel, and by this means the ſilver is purified from every metal except gold; for it is not neceſſary, on this occaſion, to remark, that a minute portion of copper, when there happens to be any in a maſs of ſilver and lead, probably eſcapes the action of the fire in cupelling gold or ſilver.

There are ſeveral ſmelting houſes at *Holywell* in *Flintſhire*, where ſilver is extracted from lead; Mr. *Pennant**

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* Tour through Wales.

has given the following account of the quantity of ſilver extracted at one of the largeſt of theſe houſes in the courſe of ſix years.

	ounces.		ounces.
Year 1754	12160	Year 1774	5693
1755	1276	1775	6704
1756	7341	1776	4347

The ſilver obtained from lead at *Holywell*, is chiefly ſold to the manufacturers at *Birmingham* and *Sheffield*. Much ſilver is alſo extracted from lead in *Northumberland*.

At Holywell they uſually work off three tons of lead at one operation, the quantity of ſilver which they procure, is variable according to the richneſs of the lead; a few years ago they were refining lead from an ore found in the *Iſle of Man*, and it gave them about 60 ounces at every operation, or 20 ounces in a ton of the lead. The litharge ordinarily obtained from three tons of lead amounts to 58 hundred weight; this litharge may either be changed into red lead by calcination, or it may be reduced into lead again by being fluxed with charcoal, or any other matter containing the inflammable principle;* but when it is *reduced* they ſeldom obtain more than 52 hundred weight of lead,† ſo that by ex-

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* Lead from litharge is, generally ſpeaking, worth five ſhillings a ton more than ore lead, as the plumbers eſteem it ſofter and fitter for making ſheet lead; yet the litharge lead from the ore of the Iſle of Man here mentioned, was found quite unfit for making ſheet lead, on account, probably, of the ore having held other metals beſides ſilver and lead.

† In the foreign works they eſtimate the loſs of weight, which the litharge ſuſtains in being

extracting the ſilver, there is a loſs of eight hundred weight in three tons of lead. It has been ſaid that the *Dutch* can extract the ſilver from three tons of lead, and not loſe above ſix hundred weight * upon converting the litharge into lead, and that this ſuperior ſkill, aided, probably, by their ſuperior induſtry, enabled them to purchaſe our lead, and to extract the ſilver from ſuch as could not be refined here with advantage: I have been informed, however, by an experienced refiner in Derbyſhire, that he could extract the ſilver without loſing quite ſo much as ſix hun-

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being reduced into lead, at a ſixth part of the weight of the litharge, or $9\frac{2}{3}$ hundred weight from 58 hundred weight of litharge. Eſſais des Mines, Tom. II. p. 401.

* Webſter's Metal. p. 233.

dred weight in three tons of lead; I make no queſtion that the loſs depends, in ſome meaſure, on the quality of the lead. It has been remarked before, that lead, which does not contain nine ounces of ſilver in a ton, is not thought worth the refining; the ſmalleſt quantity which can be extracted with profit, muſt depend much upon the price of lead, all expences attending the ſeveral proceſſes being the ſame. For eight hundred weight of lead, which may be aſſumed at a medium as the loſs ſuſtained during the operations of *refining* and *reducing*, is worth 6l. when lead is at 15l. a ton, and it is worth only 4l. 16s. when it is at 12l. a ton. The value of 27 ounces of ſilver, which we ſuppoſe to be the quantity ſeparable from three tons of lead, is 7l. 10s. 9d. at 5s. 7d. an ounce; hence, the difference between the value of the ſilver obtained, and that of the lead loſt, would, when lead is at 15l. a ton, be 1l. 10s. 9d. and when lead is as low as 12l. a ton, it would amount to 2l. 14s. 9d. In the times of Sir *John Pettus*, the uſual allowance for waſte in refining and reducing of lead, was three hundred weight in a ton, or nine hundred weight in three tons, and the lead was valued at 12l. a ton,* ſo that lead has altered very little in its price in the courſe of above one hundred years.

Silver is here valued at 5s. 7d. an ounce; this requires ſome explanation. A pound of *ſtandard* ſilver in England, conſiſts of 11 ounces and 2 pennyweights of *fine* ſilver, and of 18 pennyweights of copper; in other words, every maſs of *ſtandard* ſilver conſiſting of 40 parts by weight, is compoſed of 37 parts of *fine* ſilver, and of 3 parts of copper; the copper is called the *alloy*. All nations uſe ſome alloy both in their gold and ſilver; partly with a view of rendering theſe metals harder, and partly becauſe it would require much labour and expence to free them wholly from that ſmall portion of copper, which, in their ordinary ſtate, as fluxed from their ores, they are generally found to contain. A pound of *ſtandard* ſilver is coined into 62 ſhillings, hence the *Mint* price of an ounce of *ſtandard* ſilver would be a twelfth part of 62 ſhillings, or 5s. 2d. From hence it might be ſhewn, by the rule of proportion, that the *market* price of an ounce of *fine* ſilver, which contains no copper, will be 5s. 7d. at the leaſt. The market price of ſilver bullion does not wholly depend on the mint price, it can never be lower than that, but, from the operation of various cauſes, it may exceed it. †---*Standard* gold with us conſiſts of 11 parts of *fine* gold, and of 1 part of copper, or of a mixture of ſilver and copper; and a pound or 12 ounces of ſtandard gold, is coined into 44½ guineas; hence the price of an ounce of ſtandard gold is 3l. 17s. 10½d. and the price of an ounce of *fine* gold is 4l. 4s. 11½d. Foreign gold trinkets ſtain the hands more, and have a more coppery look than Engliſh ones; and in fact they are made of gold which is alloyed with a much greater proportion of copper, than the ſtandard gold of England; yet, when an enamel is to be fixed on gold, one of the moſt experienced of the foreign enamellers, † recommends the uſe of gold, which has the ſame alloy as the Engliſh ſtandard gold, or two parts alloy, and twenty-two parts of fine gold.

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* Fodinæ Reg. p. 10.

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† Eſſay on Money and Coins, p. 2. & 55.

Copper communicates a ſmell both to gold and ſilver. The *Roman ſpecula*, which they uſed as looking glaſſes, in *Pliny*'s time were commonly made of ſilver, but the ſilver was alloyed with much copper; for we find a cunning waiting maid in *Plautus* adviſing her miſtreſs to wipe her fingers after having handled a ſpeculum, leſt her paramour from the ſmell of her fingers ſhould ſuſpect her of having received ſilver from ſome other lover.

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† M. de Montamy, Traite des Coleurs.

Ut ſpeculum tenuiſti, metuo ne oleant argene
 tum manus.
Ne uſque argentum te accepiſſe ſuſpicetur
 Philolacles.[*]

[*] Plaut. Moſt. Act. I.

ESSAY X.

OF RED AND WHITE LEAD.

IF the reader does not know what *minium* or *red lead* is, I would wiſh him to ſend for a few ounces of it to his painter or apothecary.— Suppoſing him to have a parcel of red lead before his eyes, the firſt thing which will ſtrike him is its vivid colour verging a little towards orange; if he crumbles it between his fingers, he will find it to be an almoſt impalpable powder; if he poizes it in his hand, he will perceive it to be much heavier than either brick duſt or red ochre, with which ſubſtances it is ſometimes adulterated; if he compares it with a piece of lead, he will be aſtoniſhed how it can be either produced from lead, or be capable of being, by a very ſlight operation, *reduced* into lead again.

It has been mentioned in the preceding Eſſay, that red lead is made from *litharge* at *Holywell:* this red lead which is made from litharge is not perhaps, in all its properties, of quite the ſame kind with that which is made directly from lead; at leaſt I have been informed, that the makers of flint glaſs, who uſe much red lead in the compoſition of that glaſs, are of opinion, that the litharge red lead does not flux ſo well as that which is made from the direct calcination of lead, as is practiſed in *Derbyſhire*. There are in that county nine red lead mills or furnaces, all of which are much upon the ſame conſtruction.

The furnace is very like a baker's oven, its vaulted roof is not at a great diſtance from the bottom or floor, on each ſide of the furnace there are two party walls, riſing from the floor of the furnace, but not reaching to the roof; into the intervals between theſe walls and the ſides of the furnace the pit-coal is put, the flame of which being drawn over the party walls and ſtriking upon the roof, is from thence reflected down upon the lead, which is placed in a cavity at the bottom, by which means the lead is ſoon melted. The ſurface of melted lead, when expoſed to the open air, inſtantly becomes covered with a duſky pellicle; and this pellicle being removed another is formed, and thus by removing the pellicle, as faſt as it forms, the greateſt part of the lead is changed into a yellowiſh green powder. This yellowiſh powder is then ground very fine in a mill, and being waſhed, in order to ſeparate it from ſuch parts of the lead as are ſtill in their metallic ſtate, it becomes of an uniform yellow colour, and, when it is dried to a proper conſiſtency, it is thrown back again into the furnace, and being conſtantly ſtirred, ſo that all its parts may be expoſed to the action of the flame of the pit coal, in about 48 hours it becomes *red lead*, and is taken out for uſe.

The colour of the red lead admits ſome variety, which is occaſioned by the different degrees of heat. If the heat is too ſmall, inſtead of red it is yellow or orange coloured; if it is too great the red colour is changed into a dirty white, between theſe two extremes it is ſubject to ſome diverſity of ſhades of red, which cannot well be noticed or deſcribed, except by thoſe who are engaged in the making of it.

It has been aſſerted, that the reverberation of the flame and ſmoke upon the ſurface of the lead, is not a neceſſary circumſtance in giving it a red colour,* but that it will acquire this colour by a long calcination without coming into contact with the flame. The truth of this aſſertion I think may be doubted. I have more than once calcined lead for above 60 hours, without ſuffering the flame of the fire to touch it during any part of the proceſs, but by this method I could never obtain any thing better than a dirty red, reſembling the red of brickduſt, which is very different from the colour of red lead; and even this dirty red was changed into a yellow colour, by augmenting the degree of heat with which the lead had been calcined. The method of making red lead is very well underſtood in *England* and *Holland*, but not in *France*; and the French workmen are of opinion, that it cannot be made by the flame of wood fires. *

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* Inſtit. de Chym. par M. Demachy, p. 522.

During the making of red lead, part of it is volatilized, there riſes up from it a vapour, which attaches itſelf to the roof of the furnace, and forms ſolid lumps. Theſe lumps are of a yellowiſh white colour mixed with pale green and ſome reddiſh ſtreaks, wherein are frequently ſmall red cryſtals, reſembling ſuch as may be artificially formed by ſubliming ſulphur and arſenic together. The workmen call the whole of what is ſeparated from the lead in the form of ſmoke, ſulphur: when this ſublimed matter is detached from the roof of the furnace, the red parts

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* Mem. de l'Acad. des Scien. 1770.—Elemens de Mineral. par M. Sage. Vol. II. p. 248.

are converted, by a ſubſequent proceſs, into red lead; and the yellow ones are ſent to the ſmelting furnaces, to be run down again into lead. The quantity of this ſublimate amounts to about five hundred weight in making one hundred tons of red lead. The proportion here aſſigned is not wholly to be relied on, ſince the ſmoke ariſing from the lead forms itſelf into larger maſſes, and in leſs time, when it is not conſtantly ſwept from the roof of the furnace than when it is; and the workmen endeavour to keep the roof as free from it as they can, becauſe a ſmall portion of it injures the colour of a large quantity of the red lead with which it happens to be mixed.

A ton or twenty hundred weight

of lead generally gives twenty-two hundred weight of red lead, notwithſtanding the loſs of ſubſtance which the lead evidently ſuſtains from the copious ſmoke which ariſes from it during the operation. Some authors tell us, that the increaſe in the weight of the red lead is double what I have here mentioned: thus, *Orſchall* ſpeaking of the red lead made at *Nuremberg*, aſſures us, that 100 pounds of lead yield 120 pounds, and ſometimes even more, of red lead.* It is not impoſſible that, according to the different manners of conducting the proceſs, there may be a difference in the quantity of weight which the red lead acquires: I had my information from ſome of the moſt experienced makers of red lead in Derbyſhire. There have been great diſputes amongſt philoſophers, to what principle this increaſe of weight ſhould be aſcribed; ſome have attributed it to what they call the matter of fire; others are upon good grounds convinced, that it is owing to the abſorption of the air itſelf, or of ſome of the principles of which the air conſiſts. This hypotheſis concerning the fixation of air during the calcination of metals, is ſaid to have been firſt advanced by *John Rey*, a French phyſician, in 1630; *Dr. Hales* was partly of the ſame opinion;* and Dr. *Pemberton* very expreſsly affirms, that calcined metals receive their increaſe of weight from the air, which " by acting on the inflammable

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* Orſch. Metal. French Tranſ. p. 100.—M. Sage's Mine. Vol. II. p. 384.

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* Veget. Stat.

able ſubſtance, either in metals or other bodies, expels its from them, and unites itſelf (in part at leaſt) to the remains of the body."[*] The ingenious labours of Dr. *Prieſtley* and of M. *Lavoiſier* have confirmed the conjectures and experiments of former philoſophers, for they have clearly proved two points—firſt, that a large portion of air may be *ſeparated* from red lead, by *reducing* it to the ſtate of a metal;—and ſecondly, that a large portion of air is *abſorbed* by *lead* during the calcination, by which it is reduced to the ſtate of red lead.[†]

During the calcination of lead, it is certain, from what has been ſaid, that much of its ſubſtance is diſperſed into the air; this ſubſtance may indeed be ſeen aſcending as a ſmoke from the ſurface of the lead, if the heat be ſo great as to make it boil; and in a leſs degree of heat, the vapour which aſcends from it, may be rendered viſible, by holding over it a wet iron ladle to condenſe it. But at the ſame time that the lead loſes conſiderably of its weight by the volatilization of part of its ſubſtance, it receives ſuch an acceſſion of new matter from the air, as renders the weight of the part which remains, much greater than that of the whole lead which was expoſed to calcination. This acceſſion of aërial matter may be driven off from red lead, by reſtoring to it the inflammable principle which was conſumed during the calcination; but after this extraneous matter is driven off, by reducing the lead, we ought not to expect that the lead, which is thus brought back to its former ſtate, ſhould weigh as much as it did before it was calcined; becauſe that part of it which was volatilized and diſperſed into the air cannot be recovered. And in fact, it was obſerved in the laſt Eſſay, that three tons of lead, when converted by calcination into litharge, had loſt two hundred weight; this quantity, and, probably much more than this, had been volatilized and loſt, for the remaining fifty-eight hundred weight conſiſted partly of the earth of lead, and partly of the air which had been fixed in it during the calcination; and hence, when it was reduced, it did not give above fifty-two hundred weight. In calcining then, and reducing ſixty hundred weight of lead, there is a loſs of eight hundred weight: a great part of this loſs is rightly referred to the volatilization of the lead, but a part alſo may juſtly enough be referred to the ſcoria which remains after the reduction of the litharge into lead, that operation being ſeldom performed ſo accurately as not to leave ſome part of the litharge unreduced. I have here ſpoken of the loſs of weight, ſuſtained during the reduction of litharge, as if it was the ſame as that which red lead ſuſtains; there, probably, may be ſome difference between them, but the general inference is the ſame; and I have been informed moreover, that there is neither increaſe nor decreaſe in weight, in converting litharge into red lead.*

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[*] Pember. Chem. p. 245.

[†] Prieſtley's Exper. and Lavoiſier's Eſſays, tranſlated by Henry.

In making red lead in Derbyſhire, the workmen mix one hundred weight of *ſlag* lead with about eighteen hundred weight of *ore* lead; and they are perſuaded that this ſlag lead has a great effect, in accelerating the converſion of the other lead into an earth. *Tin*, when mixed with lead, very much promotes its calcination; and the ſlag lead has this property in common with a mixture of tin and lead, that it does not, when melted, exhibit any colours on its ſurface: may not its properties, by which it is diſtinguiſhable from ore lead, ariſe from its containing zinc or tin? We are too apt, I think, to look upon the ores of lead as containing only one metal; ſince we are certain that they all contain two, namely, lead and ſilver; and it may be, that they contain other metallic ſubſtances, particularly zinc and tin.

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* This obſervation does not accord with that of the author of the Familiar Diſcourſe concerning Mines, p. 34.——" 20 hundred weight of this litharge will produce 22 hundred weight of red lead." Another author informs us that 20 pounds of lead will by a long calcination give 25 pounds of aſhes, and that theſe 25 pounds of aſhes will, when reduced, give 19 pounds of lead. Lemery Cours de Chym. p. 145.

In converting a ton of lead into red lead, the workmen obſerve, that towards the end of the operation, a few pounds of lead are always found to remain, which cannot be changed into red lead, with the ſame facility with which ordinary lead is changed. When I was firſt informed of this circumſtance, I conſidered it in the following manner. — Derbyſhire lead, though it does not contain ſilver enough to render the extraction of it profitable, yet it generally contains five or ſix ounces in a ton: ſilver is not capable of being converted into an earth by the action of air and fire, when therefore a ton of lead is converted, as to its greateſt part, into red lead, why may not the ſix ounces of ſilver contained in that lead, be left unaltered? and may not the ſuperior difficulty of reducing the laſt portion of the lead into red lead, proceed from hence, that it is much more impregnated with ſilver, than ordinary lead is? Under the influence of this conjecture, I procured from Derbyſhire, ſome of the lead which remained un-

uncalcined in the making of red lead, and I aſſayed it for ſilver; but it did not contain more ſilver, than many ſpecimens of ore lead contained.

It has been remarked, more than once, that red lead may be *reduced* into lead, by being melted with roſin, tallow, charcoal, or any ſubſtance containing the inflammable principle. The proof of this is very eaſy; a few grains of red lead being ſcattered on a piece of red hot charcoal, will be changed into globules of lead; or if the reader burns a common red wafer in the flame of a candle, holding a piece of white paper under it; he will ſee many red hot globules falling upon the paper, and theſe globules he will find to be lead: this lead proceeds from the red lead with which ordinary wafers are coloured, being *reduced* into the ſtate of a metal, by uniting itſelf with the inflammable principle. The beſt wafers are coloured with vermilion—powdered *cinnabar*.[*]

Having been diſappointed in the expectation of finding a large proportion of ſilver, in the ſmall reſidue of lead remaining after the converſion of ordinary lead into red lead; and being unwilling to give up the notion, I was deſirous of convincing myſelf that I had not been guilty of any miſtake in the aſſay that I had made, by trying whether red lead itſelf did not contain ſilver; for if red lead contained ſilver, I ſaw no reaſon to be ſurpriſed at the reſidue, before mentioned, not containing more than I found it to do. I therefore reduced a quantity of red lead into the ſtate of a metal, by melting it with roſin; this reduced lead was carefully aſſayed more than once, and it always afforded a portion of ſilver. Hence we may conclude, that the ſilver contained in lead, though it be not ſubject to calcination during the proceſs of making red lead, is nevertheleſs mixed with the calcined lead in ſuch a comminuted ſtate, as to eſcape our ſenſes; the ſilver, probably, is ſtill in the form of ſilver, but its particles are ſo indefinitely fine, that they cannot be diſtinguiſhed in the maſs of red lead, which contains them.

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[*] Cinnabar is an ore of quickſilver; it is compoſed of quickſilver and ſulphur; generally of 7 parts of quickſilver to 1 of ſulphur.

The method of making ſlag lead

has been deſcribed before; I aſſayed this kind of lead ſeveral times, and I ſometimes obtained from it a globule of ſilver, at other times there was no appearance of ſilver. This difference in the reſult of the aſſays, is not to be attributed to any difference in the quality of the ſlag lead which was aſſayed, for all the pieces which I tried were cut from the ſame lump, but to the different degrees of heat uſed in the operation; when the fire was too ſtrong, the ſilver, I conceive, was *volatilized.* Silver I know is looked upon as a *fixed* metal, and not capable of being volatilized; and the loſs of ſilver when the fire is too ſtrong, has been attributed to its being not volatilized, but abſorbed by the *cupel*; I have no objection to this account;

but that the volatilization of ſilver on the cupel is no unwarranted conjecture, appears from hence, that in the laſt proceſs of refining lead for ſilver at Holywell, ſo much of the ſilver is carried into the chimney of the furnace, that they have procured a ſilver cup from melting the ſweepings.

A great quantity of lead is annually imported in the tea boxes from China, a Congo box contains about 10 pounds, and an Hyſon box about 4 pounds of lead; I have frequently aſſayed this lead, and always found that it contained ſilver, but not in quantity ſufficient to quit the expence of extracting it.

Pure lead is heavier than pure ſilver, and the purer the lead the greater is its weight; I calculated the weight of a cubic foot of five different ſorts of lead:

Weight of a cubic foot of	Avoir. oz.
Lead from the reduction of red lead	11460
Lead uncalcined in making red lead	11331
Lead ſmelted from an ore - - -	11262
Lead from the ſlag of a cupola furn.	11212
Lead from a tea box - - - -	11176

The experiments from which I formed this table, were repeated at different times, and the mean of ſeveral trials in the reſpective ſorts is expreſſed. A cubic foot of fine ſilver weighs 11091 ounces. *

The following aſſays of the ſeveral leads here mentioned, were made by an experienced aſſayer in London; they are very little different from thoſe

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* Cotes.

thoſe which I myſelf had made, but I was deſirous that the reader might rely upon the authority of a perſon verſed in the particular buſineſs of aſſaying, rather than upon mine.

Fine ſilver in a pound of	Grains.
Lead from the reduction of red lead	1½
Lead uncalcined in making red lead	1½
Lead ſmelted from an ore - - - -	1¾
Lead from the ſlag of a cupola furn.	1¾
Lead from a tea box - - - - - -	1¾

From comparing the two tables together, we ſee that the heavieſt lead contains the leaſt ſilver. I do not think, that perſons intereſted in knowing the quantity of ſilver contained in any particular ſpecimen of lead, ſhould reſt ſatisfied with aſſaying ſo ſmall a portion as a pound, eſpecially if no notice is taken of any weight leſs than one fourth of a grain.

White lead or *ceruſe*, is lead corroded by vinegar. Thin plates of lead are rolled up in a ſpiral form, and placed in earthen pots containing vinegar; theſe pots being ranged on proper ſtages, and their mouths being covered in ſuch a manner, as to permit the vapour of the vinegar to eſcape, and at the ſame time to prevent any impurity from falling into them, a quantity of horſe dung is thrown in amongſt them; by the heat of which, as it grows putrid, the vinegar is raiſed in vapour, and this vapour attaching itſelf to both ſides of every ſpiral of the lead, which is ſo placed as not to touch the vinegar, it corrodes the lead into white ſcales, which being beat off

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ſrom the plates, waſhed and ground in a mill, conſtitute the white lead of the ſhops, excepting that this is generally, even before it gets into the hands of the painters, adulterated with chalk. Ceruſe was formerly made by the vapour of putrid urine inſtead of vinegar. The time when this preparation of lead was firſt diſcovered is wholly uncertain; *Dioſcorides* ſpeaks of its being made in great perfection at *Rhodes*, *Corinth* and *Lacedemon*, and of an inferior ſort of it at *Puteoli*; * and *Pliny* deſcribes two ways of conducting the operation, both of which are now in uſe ‡.

The *Roman ladies* were well acquainted with the uſe of ceruſe as a coſmetic: *Plautus* introduces a waiting

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* Dioſ. Lib. V. C. 103.

‡ Lib. XXXIV. S. 54.

ing woman refuſing to give her miſtreſs either *ceruſe* or *rouge*, becauſe, forſooth, in the true ſpirit of a flattering Abigail, ſhe thought her quite handſome enough without them.* I ſuppoſe the Chriſtian ladies in the days of *St. Jerome*, were given to this pagan cuſtom, for the venerable father inveighs very forcibly againſt the uſe of *rouge* for the lips and cheeks, and of *ceruſe* for the face and neck, as incentives to luſt, and indications of unchaſte deſires. Without preſuming to explore the *arcana* of a lady's toilet, or to reveal the arts by which my fair countrywomen endeavour to improve charms naturally irreſiſtible, I would add to the admonition of St. Jerome, a caution more likely, in theſe degenerate times, to be attended to— the certain ruin of the complexion, to ſay nothing of more ſerious maladies, which muſt ever attend the conſtant application of this drug. Nor is the *magiſtery* of *biſmuth* or *Spaniſh white*, as it is called, much leſs pernicious than ceruſe, notwithſtanding its being in ſuch repute in London, that the chemiſts can hardly prepare it faſt enough to ſupply the demand for it.* But if, as is moſt probable, they will neglect this caution, I warn them, however, to forbear the uſe of ſuch waſhes at Harrowgate, Moffat, and other places of the ſame kind, leſt they ſhould be in the ſtate of the unlucky fair one, whoſe face, neck, and arms were ſuddenly deſpoiled of all their beauties, and changed quite black by a ſulphureous water. Indeed, all phlogiſtic vapours, and even the ſun itſelf, tends to give both the magiſtery of biſmuth, and ceruſe, a yellow colour: this obſervation may explain a line a line in *Martial*, where a *ceruſed* lady is ſaid to fear the ſun.*

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* —— non do, ſcita es tu quidem,
Nova pictura interpolare vis opus lepidiſſimum,
Non iſtanc ætatem oportet pigmentum allem attingere,
Neque ceruſam, neque melinum, neque alium ullam offuciam.
Plaut. Moſt. Act. I.

Quid faciat in facie Chriſtianæ purpuriſſus et ceruſa, quorum alterum ruborem genarum, labiorumque mentitur, alterum candorem oris et colli, ignis juvenum, fomenta libidinum, impudicæ mentis judicia. Hieron. ad Fuſcum.

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* The magiſtery of biſmuth is made by diſſolving that ſemimetal in aqua fortis, and precipitating the diſſolved biſmuth from the acid, by water.

Other fluids, beſides the vapour of vinegar, corrode lead into a kind of ceruſe. When plumbers ſtrip the roofs of churches, or other buildings covered with lead, which has lain undiſturbed for many years, they uſually find that ſide of the lead which is contiguous to the boards, covered with a white pellicle, as thick ſometimes as an half crown; this pellicle is corroded lead, and is as uſeful for painting, and other purpoſes, as the beſt white lead. The lead on the ſouth ſide of any building is found to abound moſt with this white cruſt; that on the north ſide having very little, or none at all of it. It is believed alſo, that lead which lies on deal boards, is not ſo apt to be covered with this white incruſtation, as that which lies upon oak; if there be any truth in this obſervation, it may, perhaps, be explained from hence, that oak contains a much ſtronger acid than deal, and this ſtrong acid being diſtilled, as it were, by the heat of the ſun in ſummer, attaches itſelf to the lead and corrodes it: or this corroſion may be the effect of the ſun and air, which, by their conſtant action, calcine or corrode the lead; and this calcined lead not being waſhed off by the rain, may, in the courſe of a great many years, form the cruſt here ſpoken of. It might be worth while, in a philoſophical view, to examine more minutely than has been done, the difference between old lead which has loſt ſome of its parts by long expoſure to the air, and new lead. The plumbers have aſſured me that if a pig of old lead, and an equal pig of new lead, be put together into the ſame iron pot, and expoſed to the ſame degree of heat, the new lead will be melted much ſooner than the old lead. Another difference betwixt them, reſpects the quickneſs with which they may be reduced to a *calx*, the new lead being obſerved to calcine much faſter than the old.

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* —— cretata timet Fabulla, nimbum,
Ceruſata timet Sabella, ſolem.
Mar. Ep. Lib. II. E. XLI.

Neither ceruſe, nor litharge, nor minium, have any taſte, but any of theſe ſubſtances being boiled in diſtilled vinegar, which has an acid taſte, will be diſſolved in it; and the ſolution being cryſtallized will give one of the ſweeteſt ſubſtances in nature, called *Saccharum Saturni*, or ſugar of lead. It is this property which lead has of acquiring a ſweet taſte by ſolution in an acid, that has rendered it ſo ſerviceable to thoſe wine merchants who, reſpecting their own profit more than the lives of their cuſtomers, have not ſcrupled to attempt recovering wines, which had turned ſour, by putting into them large quantities of ceruſe or litharge. I believe this adulteration is puniſhed with death in ſome parts of *Germany*; and it is to be wiſhed that it met with that puniſhment every where. In 1750 the *farmers general* in *France* being aſtoniſhed at the great quantities *de vin gaté* which were brought into *Paris*, in order to be made into vinegar, redoubled their reſearches to find out the cauſe of the great increaſe in that article; for near thirty thouſand hogſheads had been annually brought in for a few years preceding the year 1750, whereas the quantity annually brought in forty years before, did not exceed 1200 hogſheads. They diſcovered, that ſeveral wine merchants, aſſuming the name of vinegar merchants, bought theſe ſour wines (which were ſtill rendered more ſour by the cuſtom of pouring into each hogſhead ſix pints of vinegar before it was ſold,) and afterwards, by means of litharge, rendered them potable, and ſold them as genuine wines.*

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* Exam. Chy. de Differ. Subſ. par. M. Sage, p. 157.

Our Engliſh vintners, there is reaſon to fear, are not leſs ſcrupulous in the uſe of this poiſon than the French wine merchants; for it not only corrects the acidity of ſour wines, but it gives a richneſs to meagre ones, and by this property the temptation to uſe it is much increaſed.

The reader may ſoon furniſh himſelf with the means of detecting lead when diſſolved in wine. Let him boil together in a pint of water, an ounce of quicklime and half an ounce of flowers of brimſtone, and when the liquor, which will be of a yellow colour, is cold, let him pour it into a bottle, and corking it up, reſerve it for uſe. A few drops of this liquor, being let fall into a glaſs of wine or cyder containing lead, will change the whole into a colour more or leſs brown, according to the quantity of lead which it contains; if the wine be wholly free from lead, it will be rendered turbid by the liquor, but the colour will be rather a dirty white than a blackiſh brown. *Van Helmont* * was of opinion, that *Paracelſus* made no vain boaſt, in ſaying that he could cure two hundred diſeaſes by preparations of lead; but he does not tell us of the many hundred perſons he, probably, ſent to their graves by his attempt. But it is beyond my ability, and falls not within my deſign, to diſcuſs either the ſalubrious or poiſonous qualities of lead; eſpecially as the labours of Sir *G. Baker* * and Dr. *Percival* † have ſo fully illuſtrated that ſubject.

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* Adeo ut non fruſtra Paracelſus glorietur ſolo plumbo forte ducentas morborum claſſes ſuperare poſſe. Helm. Op. p. 561.

Having accidentally heard, during the printing of this volume, that Dr. *Prieſtley* had diſcovered a method of reducing red lead to its metallic form, by melting it, in contact with inflammable air, by means of a burning glaſs, I was very deſirous of having ſo remarkable a fact confirmed by other experiments. But being prevented by a bad ſtate of health from venturing into an elaboratory myſelf, I communicated my wiſhes and ideas to an ingenious gentleman of this univerſity, ‡ who has for ſome years been cultivating chemiſtry with a proa proper degree of enthuſiaſm, and he has ſucceeded in reducing red lead by means of inflammable air in the following manner. To one end of a glaſs tube, into the middle of which ſome red lead had been put, an empty bladder was tied; to the other end a bladder full of inflammable air, obtained from a ſolution of iron in the acid of vitriol, was faſtened very cloſe: that part of the tube, in which the red lead was principally lodged, being heated almoſt red hot, by being held over a ſmall crucible full of burning charcoal, the inflammable air was preſſed out of the bladder; at its firſt paſſage through the tube the red lead became brown, as if it had been mixed with ſome *oleaginous* particles; and by preſſing the bladders alternately for a ſhort a ſhort ſpace of time, the red lead was reduced into ſmall globules of lead; the quantity of inflammable air was ſenſibly diminiſhed, a part of it having been abſorbed by the red lead, when it became a metal.

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* Med. Eſſ. † Eſſ. on the Poiſon of Lead.

‡ Rev. Mr. Milner, A. M. Fellow of Queen's College.

Occaſion was taken in another place to remark, the inflammable air, as a conſtituent part of combuſtible bodies, bore a great reſemblance to phlogiſton, * and a doubt alſo has been expreſſed, whether the phlogiſton of metallic ſubſtances be not an elaſtic inflammable fluid; this experiment, in which lead is reduced by abſorbing inflammable air, tends very much to ſtrengthen that hypotheſis, and I doubt not we ſhall ſee reaſon to admit it without heſitation, when the ſubject has been more inveſtigated

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* Vol. II. p. 331.

veſtigated; at preſent I do not know whether it has been proved that the *whole* of any definite quantity of inflammable air can be abſorbed by a metallic earth; nor, if it cannot, what the nature of the remainder is: but the removal of theſe, and other doubts, will be beſt accompliſhed by the ability of him, to whom we owe the firſt ſuggeſtion, of the phlogiſton of metallic ſubſtances being an inflammable air.

END OF VOL. III.